FINAL REPORT ON THE DETERMINATION OF APIOS PRECIPITATION CHEMISTRY FROM THE CLIMATOLOGY OF REGIONAL PRECIPITATION EPISODES

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Final Report on the Determination of APIOS Precipitation Chemistry from the Climatology of Regional Precipitation Episodes

prepared for the Ontario Ministry of the Environment

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EXECUTIVE SUMMARY

OBJECTIVE

The complexity of Eulerian long range transport models presently being developed in Canada and the U.S. has resulted in questions about applying such large computer models to derive seasonal and annual sulphate or nitrate deposition. Comprehensive Eulerian models are designed to simulate the physical chemical and transport processes of individual pollution episodes in detail. These models require very detailed meteorological input data. The processing of that meteorological data and the subsequent running of the Eulerian model requires significant amounts of time on large, fast computers.

Several methods have been suggested for obtaining long-term deposition results for Eulerian models. These proposals include:

1. A brute force approach where the comprehensive Eulerian model is run with a year long meteorological data set. This would require substantial computer and manpower resources.

2. Development of simplified "engineering models" which would be calibrated against the comprehensive Eulerian model for a number of individual pollution episodes. The engineering models would then be used to derive annual and seasonal deposition.

3. Development of a climatology of precipitation episodes for a given geographic region with subsequent derivation of physical/statistical relationships between the

precipitation climatology and observed precipitation chemistry. The comprehensive Eulerian model would be run for a number of representative episodes during a year. Seasonal and annual deposition totals would then be derived by using the climatological data for the year to extrapolate from the limited number of model runs.

The objective of this report was to investigate the feasibility of the third method for deriving long-term deposition.

APPROACH

A comprehensive climatology of daily precipitation events for four regions of Ontario for 1982 and 1983 was produced. This data set included 16 discrete and 18 continuous precipitation climatology descriptors derived from surface and 850 mbar weather maps and trajectory plots, regionally representative hourly surface meteorological data, nearby upper air soundings and precipitation data from hourly and daily climatological records. Using 1982 as the base year, statistical comparisons were made to the APIOS (Acid Precipitation in Ontario Study) observed daily precipitation chemistry data. For each of the four regions the best climatological parameters for representing precipitation chemistry within that region were selected and statistical models for estimating SO_4 and NO_3 precipitation concentrations were produced.

These statistical models were then used to classify the precipitation periods in each region into eight categories ranging low to high SO_4 or NO_3 concentrations. The category ranges were selected to give approximately the same number of precipitation events in each category.

The final step in the feasibility study documented in this report was to compare predicted annual and seasonal SO_4/NO_3

deposition at individual stations with the observed deposition at that station. The predicted values make use of 86 selected days during the year (from 3 to 11 days in each month of the year). Data for these days were used to produce precipitation weighted averaged concentrations for each climatological category. Using the climatological classification of each event in the year along with the above average SO_4/NO_3 concentrations for the eight categories, seasonal SO_4/NO_3 depositions were estimated. These estimated deposition results were then compared with the observed deposition to see how useful the climatological stratification was.

CONCLUSIONS AND FUTURE WORK

The principal conclusions of this report can be summarized as follows:

1. Although many of the meteorological parameters were correlated with either SO_4 or NO_3 precipitation chemistry, the correlation coefficients were usually less than 0.4. Also a climatological descriptor that was significant for SO_4 in a particular region would not necessarily be important for NO_3 in that same region.

2. The statistical models incorporating the best two discrete and the best two continuous meteorological descriptors gave correlation coefficients for each region which ranged from 0.44 to 0.83 for SO_4 in warm months and 0.58 to 0.74 for SO_4 during cold months. Corresponding figures for NO_3 were 0.56 to 0.82 during warm months and 0.56 to 0.70 during cold months. The statistical models had the most difficulty in southwestern Ontario where average concentrations were the highest.

3. Analyses indicated that the best climatological variables for SO_4 were not necessarily the best for NO_3. Also, better statistical correlations were found when each region was examined separately when determining the best set of variables. In some cases such differences might be related to the relationship of the receptor region to source regions. In other cases it might simply be a matter that many of the meteorological variables were inter-related with one slightly better for a particular data set. A list of the best overall predictors of precipitation chemistry was produced.

4. Comparisons of seasonal or annual deposition extrapolated from a limited data set versus actual observations showed good overall agreement. Extrapolated seasonal depositions were derived in two ways in the report. In one set of calcaulations the data was stratified into eight climatic categories before doing the extrapolations. The objective was to explain as much of the variance as possible with the stratification and thus improve the overall prediction. In the second set of calculations no data stratification was performed so the deposition predictions were based only on extrapolating to the total precipitation in the season. The two methods for predicting seasonal deposition performed equally well.

   The main factor affecting the accuracy of the extrapolated deposition was the percentage of the precipitation cases and of the precipitation amount included in the limited data set. Seasonal deposition predictions for overall regions were usually within 5 to 15% of the observed values. For individual stations the worst results were produced for stations where the limited data set most poorly sampled the precipitation events at that station.

As the region for which you are attempting to estimate deposition gets larger the selection of modelling days becomes more difficult. This means that any method of extrapolating from limited model runs to seasonal depositions can only be expected to produce reasonable results over a limited area.

The lack of improved performance when climatological classification was included when doing the extrapolations could be caused by the small number of events included in each category (i.e. eight categories were used). As future work, this stage of the exercise will be repeated using different climatological groupings.

As an addendum to this report analyses were carried out with 1983 data. The predictions were based on 71 days of data. Overall the error were 10 to 15% and again the performance was not improved by climatological classification.

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OBJECTIF

La complexité des modèles eulériens de transport à grande distance actuellement élaborés au Canada et aux États-Unis a suscité des questions sur la façon de mettre en application ces grands modèles informatiques pour calculer les dépôts saisonniers et annuels de sulfate ou de nitrate. Les modèles eulériens complets permettent une simulation détaillée des processus physico-chimiques et des processus de transport liés à chaque cas de pollution. Ces modèles nécessitent l'obtention de données météorologiques très précises. Pour traiter ces données météorologiques et exécuter par la suite le modèle eulérien, il faut disposer de gros ordinateurs rapides et de beaucoup de temps.

On a proposé plusieurs méthodes pour obtenir des résultats concernant les dépôts à long terme à partir de ces modèles. Ces propositions sont les suivantes :

1. Une méthode brute prévoyant l'exécution du modèle eulérien complet à partir de l'ensemble des données météorologiques d'une année. Ce procédé nécessiterait des ressources informatiques et humaines importantes.

2. La mise au point de modèles techniques simplifiés qui seraient étalonnés d'après le modèle eulérien complet et appliqués à un

certain nombre de cas de pollution pris séparément. Ces modèles serviraient ensuite à calculer les dépôts annuels et saisonniers.

3. L'élaboration d'une climatologie des cas de précipitations pour une région géographique donnée permettant par la suite de trouver des liens physiques ou statistiques entre l'aspect climatologique des précipitations et l'aspect chimique des précipitations observées. Le modèle eulérien complet serait exécuté pour un certain nombre de cas représentatifs durant l'année. Le total des dépôts saisonniers et annuels serait alors obtenu à l'aide des données climatologiques de l'année en question par extrapolation à partir du nombre restreint d'exécutions du modèle.

Le présent rapport examine la possibilité d'employer la troisième méthode pour calculer les dépôts à long terme.

MÉTHODE

On a produit une climatologie détaillée des précipitations quotidiennes de 1982 et 1983 pour quatre régions de l'Ontario. Cet ensemble de données comprend 16 descripteurs climatologiques discrets et 18 descripteurs continus obtenus à partir des cartes météorologiques en surface et à 850 millibars et des graphiques des trajectoires, des données météorologiques horaires des observations en

surface représentatives des régions, des sondages aérologiques et des données sur les précipitations tirées de relevés climatologiques horaires et quotidiens. En prenant 1982 comme année de référence, on a procédé à des comparaisons statistiques avec les données chimiques sur les précipitations quotidiennes figurant dans l'Étude sur les précipitations acides en Ontario. Pour chacune des quatre régions, on a relevé les paramètres climatologiques représentant le mieux la composition chimique des précipitations et on a produit des modèles statistiques permettant d'estimer les concentrations de SO_4 et de NO_3.

Ces modèles statistiques ont ensuite servi à classer les cas de précipitations de chaque région en huit catégories, selon la concentration de SO_4 ou de NO_3. Les valeurs limites des catégories ont été choisies afin qu'il y ait environ le même nombre de cas de précipitations dans chaque catégorie.

La dernière étape de l'étude, consignée dans le rapport, consistait à comparer les dépôts annuels et saisonniers de SO_4 et de NO_3 prévus à chacune des stations avec les dépôts observés à ces mêmes stations. Les chiffres prévus portaient sur 86 jours choisis durant l'année (de 3 à 11 jours pour chaque mois de l'année). Les données concernant ces journées ont permis d'établir les concentrations moyennes pondérées pour chaque catégorie climatologique. On a pu ainsi estimer les dépôts saisonniers de SO_4 et de NO_3 d'après la

classification climatologique de chaque cas de précipitations et d'après les données sur les concentrations moyennes de SO_4 et de NO_3 pour les huit catégories. Par la suite, on a comparé ces estimations aux dépôts observés pour déterminer l'utilité de la stratification climatologique.

CONCLUSIONS ET TRAVAIL À ACCOMPLIR

Voici les principales conclusions du rapport :

1. Bien qu'un grand nombre de paramètres météorologiques aient été mis en corrélation avec les concentrations de SO_4 ou de NO_3, les coefficients de corrélation étaient habituellement inférieurs à 0,4. De plus, un descripteur climatologique qui était important pour les concentrations de SO_4 dans une région donnée ne l'était pas nécessairement pour les concentrations de NO_3 dans la même région.

2. Les modèles statistiques comprenant les deux meilleurs descripteurs météorologiques discrets et les deux meilleurs descripteurs continus ont donné, pour chaque région, des coefficients de corrélation allant de 0,44 à 0,83 durant la saison chaude et de 0,58 à 0,74 durant la saison froide, en ce qui a trait au SO_4. Pour le NO_3, les coefficients

correspondants variaient de 0,56 à 0,82 durant la saison chaude et de 0,56 à 0,70 durant la saison froide. C'est dans le sud-ouest de l'Ontario, où l'on retrouve les concentrations moyennes les plus élevées, qu'il a été le plus difficile d'établir des modèles statistiques.

3. Selon les analyses, les variables climatologiques les plus appropriées pour le SO_4 ne le sont pas nécessairement pour le NO_3. En outre, on a pu établir de meilleures corrélations statistiques en examinant chaque région séparément pour déterminer les variables les plus pertinentes. Dans certains cas, les différences pouvaient être reliées aux rapports entre la région réceptrice et les régions émettrices. Dans d'autres cas, les différences pouvaient être dues au fait qu'un grand nombre de variables météorologiques étaient reliées entre elles et que l'une d'entre elles était un peu plus appropriée pour un ensemble particulier de données. On a alors produit une liste des variables servant le mieux à la prévision de la composition chimique des précipitations.

4. Il y a eu, dans l'ensemble, une bonne concordance entre, d'une part, les dépôts saisonniers ou annuels extrapolés d'après un ensemble de données limité et, d'autre part, les observations réelles. L'extrapolation des dépôts saisonniers a été obtenue de deux façons dans le rapport. Dans une première série de calculs, on a classé les données selon huit catégories climatiques avant d'effectuer les extrapolations. Cette méthode visait à expliquer

le mieux possible les écarts grâce à la stratification et à améliorer ainsi la prévision globale. Dans la deuxième série de calculs, aucune stratification n'a été effectuée; les prévisions de dépôts étaient uniquement fondées sur l'extrapolation des données portant sur les précipitations totales dans la saison. Ces méthodes permettent toutes deux une bonne prévision des dépôts saisonniers.

Le pourcentage des cas et de la hauteur de précipitations compris dans l'ensemble de données limité constitue le principal facteur influant sur l'exactitude des dépôts extrapolés. Les prévisions de dépôts saisonniers variaient habituellement de 5 à 15 pour 100 par rapport aux dépôts observés. Dans chacune des stations, les pires résultats sont apparus dans les cas où les précipitations étaient le plus mal représentés dans l'ensemble de données limité.

Plus la région dans laquelle on essaie de prévoir les dépôts s'élargit, plus il devient difficile de choisir des journées types. Cela signifie que toute méthode visant à extrapoler, à partir de données limitées, des prévisions de dépôts saisonniers peut vraisemblablement produire des résultats valables uniquement s'il s'agit de secteurs restreints.

Le petit nombre de cas inclus dans chaque catégorie (on a utilisé huit catégories) pourrait expliquer le fait que les résultats n'aient pas été meilleurs lorsqu'on a ajouté la classification climatologique à l'extrapolation. Dans un prochain travail, on recommencera cette étape en se fondant sur des groupes climatologiques différents.

Vous trouverez en supplément des analyses menées à partir de données de 1983. Les prévisions sont fondées sur les données de 71 jours. Dans l'ensemble, le taux d'erreur varie de 10 à 15 pour 100; là encore, la classification climatologique n'a pas permis d'obtenir de meilleurs résultats.

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1. Introduction

There are in existence models for the long range transport, transformation, and deposition of airborne pollutants which are necessarily complex and expensive to run. If they were to be applied for the determination of seasonal and/or annual averages of pollutant deposition amounts, the continued operation of these models over the time period of the averaging calculations would be prohibitively expensive. There is, however, and alternative to this brute force approach. If there was a climatology of precipitation episodes for one year or longer, it may be possible to relate a limited set of complex model runs on an episodic basis to the precipitation climatology for the same geographical area. This could conceivably permit the extension of the results from the limited set of model runs to a much longer time frame by means of physical/statistical relationships to the overall weather statistics.

With a view towards accomplishing the objective described above in principle, this study was carried out to test the feasibility of using meteorological parameters to produce SO_4 and NO_3 deposition statistics in Ontario.

The basic approach had several aspect to the work. It was first necessary to divide the province into approximately homogeneous regions according to the meteorology and the distribution of pollutant deposition stations within the Acid Precipitation in Ontario Study (APIOS) network. The base year was then selected for meteorological analysis and comparison to the APIOS measurement data for SO_4 and NO_3 during the same time period. Statistical analyses were carried out on selected meteorological parameters and deposition data for the possible development of a model which could predict deposition values on the basis of the selected storm parameters. A second year's analysis could then be carried out and the results from the first year's study could be tested on the second year's analyses as an independent data set.

2. Meteorological Analysis

The base year selected for study was 1982, with 1983 to be used as a test year for the results for the first year of study. Following this decision, it was necessary to: i) develop storm classification schemes to be used for analysis, ii) acquire the appropriate meteorological data for review, iii) analyze the available data according to selected parameters and develop the analysis database, iv) perform numerical and statistical experiments to determine relationships (if any) between the meteorological and deposition data, and v) generate deposition statistics from meteorological data using the relationships found in iv).

A survey was carried out on the various methodologies available. Based on a literature review as well as discussions with other meteorologists and physical scientists, a set of procedures for use in the storm analysis and classification phase of this study was developed. These are reproduced below in 9 specific steps.

1. Fix boundaries for all regions.

2. From the APIOS data set for 1982, determine the days in each region when precipitation fell and measurements of sulphate and nitrate concentrations were recorded and deemed reliable.

3. Determine the meteorological stations which lie in each region. There were 4 groupings of surface stations per region to reflect the 4 different types of observations considered. They were:

   - hourly and synoptic observations

   - recording raingauge data

   - daily precipitation totals

   - snowfall amounts as measured with a Nipher gauge

4. Acquire hourly data from appropriate stations for the days of interest.

5. From the data in Step 4, define the hours which comprise the precipitation event for each region for each day of interest. The average temperature, dewpoint, wind, and predominant clouds and weather for each precipitation event was determined.

6. From synoptic surface and upper air maps, characterize the type of synoptic system, the track of the controlling low pressure system, and the airmass(es) involved.

7. From the trajectory analysis, determine the sector and distance of the air parcel trajectory 24 and 48 hours before the precipitation event.

8. Determine representative upper air soundings for each precipitation event and calculate precipitable water, a stability index, and analyze moisture profiles to get cloud base height, cloud top, and cloud thickness.

9. For each region, obtain the following precipitation data. Analyze the recording rain gauges to get average rainfall rates, maximum rainfall rates, and average duration of precipitation events for each day of interest. From the daily precipitation amounts, get the average daily precipitation amount and the percentage number of stations receiving precipitation. From the snowfall data (stations with Nipher gauges), determine the average daily snowfall and snowfall rate (snow amount per 6 hours at the synoptic station).

The province of Ontario was divided into four regions (Southwestern, Central, Southeastern, and Northwestern) for the purpose of this study. A summary of the APIOS, hourly, synoptic, and climatological stations within each of the study regions is given in Appendix A. Appendix B lists the 25 different meteorological parameters abstracted from the data for the statistical experiments. It was necessary to resolve which stations could be considered representative of the APIOS station (if rainfall is not measured close by), or alternatively, representative of the region. This could only be done after examination of the data.

3. Climatological Data Analysis

This section of the report deals with the specifics of the data analysis and the statistical results subsequently carried out.

3.1. Synoptic Analysis

In carrying out the synoptic analysis of the meteorological data, the following procedures were followed.

i) All significant hourly weather reports for 1982 for the AES stations in the 4 regions were printed out using the MOE IBM computer.

ii) Using this printout and the Ontario Weather Centre surface analyses (every 6 hrs), the U.S. Weather Bureau daily surface analysis and 500 mb map (once per day at 1200Z), and the CMC 850 mb analyses (00 and 12Z) the following was obtained for each region for each day of interest:

- synoptic type (as in the planning report with the addition of a 7th type, namely a warm and cold front)
- track of the controlling low (as in the planning report with the addition of a Hudson Bay low category)
- predominant airmasses (up to 2 of the 5 specified)
- the time of the precipitation event and the most representative hourly station
- the most representative upper air station and the corresponding time of observation

iii) From the representative times determined from the previous step, surface and 850 mb trajectories were analyzed for the following:

- the sector from which the air originated 24 and 48 hr previous (octants numbered counterclockwise beginning in the NNW)
- the range of the air parcel 24 and 48 hrs previous (divided into 200 km segments)

3.2. Surface Analysis

i) The data from the most representative hourly station for the time of the precipitation event, as previously determined, was displayed using the IBM AT with software specifically developed for this purpose (program MDASHR).

ii) Subjective judgments were then made to try to characterize the precipitation event in terms of the nature of the precipitation (rain, snow, freezing precipitation and mixed precipitation), the type of precipitation (continuous or convective), and the predominant cloud type (towering cumulus, altocumulus, altostratus, cumulonimbus, cumulus, nimbostratus,stratocumulus, or stratus) with its reported base . The judgments focussed on the reports which indicated that the most significant precipitation was being observed.

iii) The time of the most significant precipitation was reassessed and for that time period, the average surface temperature, dewpoint, and wind were calculated.

3.3. Upper Air

i) Data from the most representative upper air station, as previously determined, was displayed using the IBM AT and program MDASUP (only standard levels were available).

ii) The 850 mb temperature and wind were selected, precipitable water ($q\Delta p/g$) and totals index ($t_{850}-t_{500}+t_{d850}-t_{700}+t_{d700}$) were calculated where q is the average mixing ratio in Δp, p is pressure, g is gravity, and t and t_d are the temperature and dewpoint at the indicated pressure levels in mb).

iii) Cloud top was subjectively determined from an examination of the temperature-dewpoint spreads where a general rule of $t-t_d$ of less than 4°C indicated the presence of cloud.

3.4. Rainfall

i) The 4 regions were gridded by latitude and longitude and the climatological stations assigned their appropriate grid within the region. The Southwest region was divided into 10 subregions, the Central into 12 subregions and the Southeast and Northwest regions into 7 and 6 subregions respectively (see Figures 3.1 and 3.2).

ii) The subregions were weighted according to their areal extent. A weighting of 1.0 indicated that the subregion was a degree of latitude by a degree of longitude in dimensions. A weighting of less than one indicated that part of the degree of latitude by degree of longitude area fell outside the region in question (e.g. over water). Table 3.1 gives the weightings and the number of hourly and daily reporting rainfall stations in each of the subregions

iii) Eight precipitation fields were examined, namely maximum rainfall rate in mm/15 min, mm/30 min, mm/hr, duration of precipitation (hrs), average hourly rate of the precipitation, daily amount, maximum 6 hr amount, and the proportion of stations receiving rainfall. For each field for each region for each day the averages

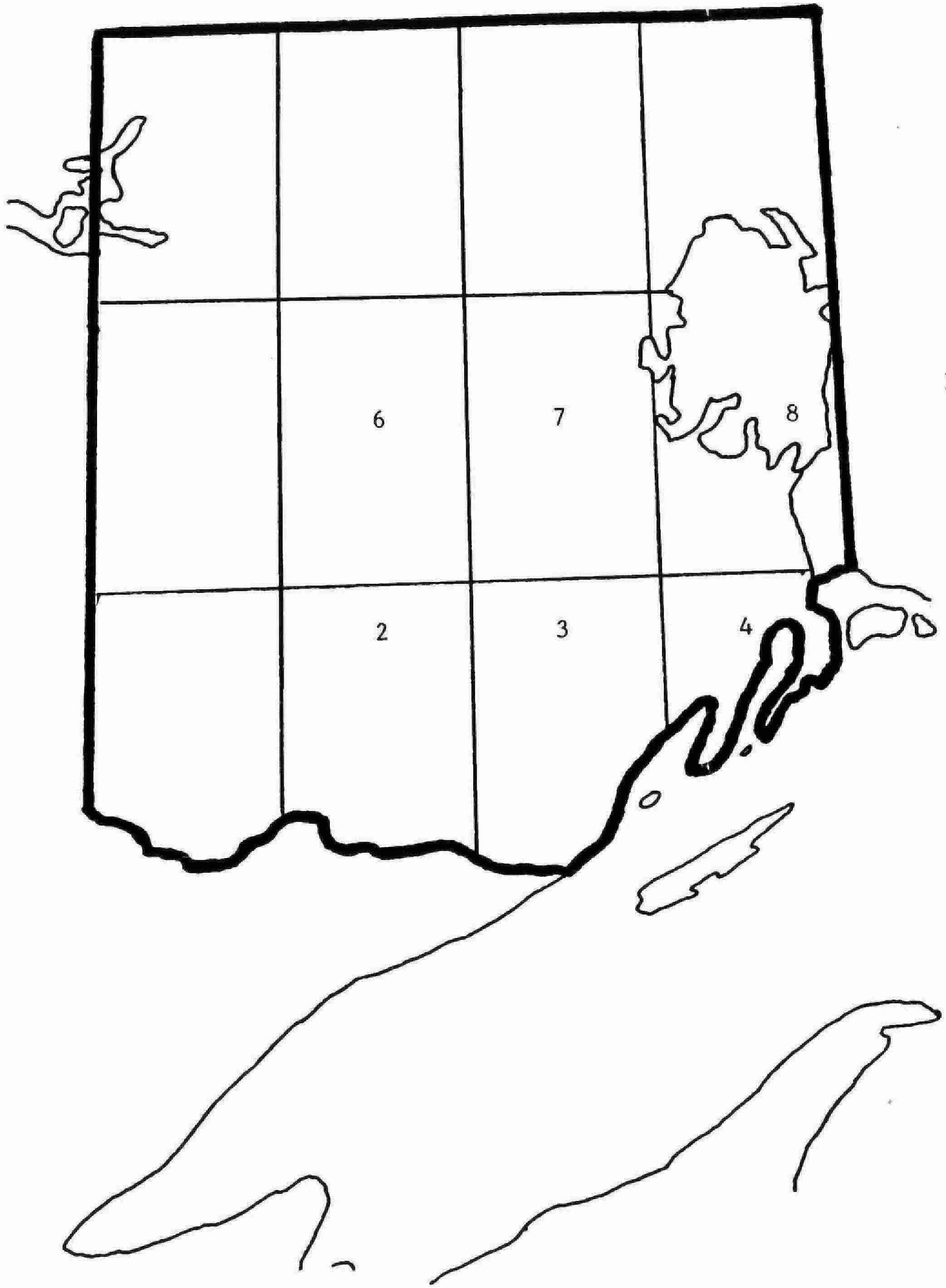


Figure 3.1 Northwestern region of the APIOS study area.

Figure 3.2 Central, Southwestern, and Southeastern regions of the APIOS study area.

REGION	SOUTHWEST			CENTRAL			SOUTHEAST			NORTHWEST		
	WT	TYPE H	D	WT	TYPE H	D	WT	TYPE H	D	WT	TYPE H	D
SUBREGION												
1	.75	4	12				1.00	5	10			
2	.50	2	8	.17	1	2	.88	3	14	.85	0	1
3	.33	3	12	.10	1	8	.31	2	6	.88	1	6
4	.14	1	4	1.00	3	21				.38	0	1
5	.03	1	1	1.00	4	20	.97	1	7			
6	.81	1	14	.30	1	4	.63	0	6	1.00	1	2
7	1.00	11	31	.25	1	2	.50	4	10	1.00	0	2
8	.71	23	77	.38	0	1	.33	1	7	1.00	1	2
9				1.00	1	8						
10	.28	0	1	1.00	3	8						
11	.50	0	2									
12				.75	0	4						
13				.75	1	5						
14				.75	1	5						

Table 3.1: Weightings for the subregions of the 4 main regions and the number of hourly (H) and daily (D) rainfall stations in each subregion.

for the subregions were first determined. Then using the weightings for the subregions, the regional average was obtained. In doing so standard deviations of the various precipitation fields by subregion and by region were also obtained.

3.5. Transfer to MOE IBM Computer

All the various fields were merged into 4 data sets (1 per region) and transferred to the IBM Computer in Downsview. The record length was 173 characters and the list of variables and the format was the following:

	1x
month	i2
day	i3
synoptic type	i3
track of low	i2
airmass(es)	1x,a6
24 hr sector of 850 mb trajectory	1x,i3
24 hr range of 850 mb trajectory	i3
48 hr sector of 850 mb trajectory	i3
48 hr range of 850 mb trajectory	i3
24 hr sector of surface trajectory	i3
24 hr range of surface trajectory	i3
48 hr sector of surface trajectory	i3
48 hr range of surface trajectory	i3
type of precipitation	i2
nature of precipitation	i2
predominant cloud type	i4
height of cloud base (m)	f6.0
surface temperature (°C)	f6.1
dewpoint (°C)	f6.1
surface wind direction (deg)	f5.0
surface wind speed (m/s)	f5.1
850 mb temperature (°C)	f6.1
850 mb wind direction (deg)	f5.0
850 mb wind speed (kts)	f5.0
cloud top height (m)	f8.0
precipitable water (mm)	f7.2
total totals index	f7.2
average maximum rate mm/15 min	f7.2
average maximum rate mm/30 min	f7.2
average maximum rate mm/hr	f7.2
average duration of precipitation (hr)	f7.2
average hourly rate of precipitation (mm/hr)	f7.2
average precipitation amount (mm)	f7.2
average maximum 6 hr amount (mm)	f7.2
percentage of stations reporting precipitation	f7.2

Note: missing data is indicated by 9's.

3.6. Problems in Data Analysis

The following is a list of the most apparent problems that occurred in trying to relate the meteorological data to the APIOS data collected.

i) Imprecise precipitation times between neighbouring APIOS stations

ii) Non-uniform on/off times of charts between APIOS stations and between days at the same station.

iii) APIOS observations not always taken daily when precipitation observed.

iv) A good deal of hourly data was missing.

v) Spurious values for the hourly data occasionally appeared (values not correct but not specified as missing)

vi) No special weather reports at the hourly stations were available

vii) The upper air data only contained the standard levels and not the significant levels as well.

4. Results and Discussion

The 33 meteorological variables available for this study can essentially be divided into 6 types. The first 3 are categorical variables.:

- synoptic situation (synoptic type, track of low)
- a description of the previous history of the air (airmass type, trajectories)
- a characterization of the clouds and weather (type and nature of precipitation, cloud type)

The next 3 are continuous variables:

- a description of airmass characteristics (temperature, dewpoint,precipitable water, totals index, wind speeds)
- a description of the clouds (clouds base, top, and thickness)
- rainfall characteristics

The goal of the analysis is to find which subset of these variables is strongly associated with the sulfate and nitrate measurements taken in the regions. If a sufficiently strong relationship is found, then a statistical model can be constructed to predict the sulfate and nitrate measurements.

4.1 General Results

A summary of the statistics derived from available data for the four regions is given in Appendix C for each of the meteorological parameters abstracted.

A general comment regarding the differences between the synoptics of the northwest region and the other 3 is that the northwest region has many more occluded systems and fewer fronts. It is more affected by the Alberta lows and less influenced by the Colorado systems than the other 3 regions. An analysis of variance was performed on both the sulfate and nitrate measurements in the four regions to test for statistically significant differences. For SO_4, the F value (the ratio of the between-column variance to the between-row variance in a matrix of SO_4 readings by region) was 29.40, giving a significance probability of 0.0001, i.e. this F value would be exceeded only 1 in 10000 times if the SO_4 means of the 4 regions were in fact equal. To further examine which means were statistically significant, Duncan's Multiple Range Test (run using the ANOVA routine on SAS User's Guide: Statistics 1982 Edition pg 122) indicated that the means which were significantly different at a significance level of 0.05 were the northwest region with the other 3 regions, and the central and southwest regions.

For the nitrate measurements, the F value was 33.73 indicating a significance value of 0.0001. Duncan's Multiple Range Test in this case showed that the nitrate readings in the northwest and the central were each different from the other 3

regions while there was no difference between the southeast and southwest measurements (at a 0.05 significance level).

4.2. Southwest Region

Due to the higher density of rainfall stations, closer proximity of upper air stations, and the accessibility of a 24 hr reporting hourly station amongst the APIOS sites (London), the relationship between the meteorological variables and the sulfate and nitrate measurements were examined in great detail for the southwest region. It was felt that any meaningful relationships between the SO_4 and NO_3 and the meteorological variables would most likely be found in this region and greater confidence could be given to these results.

4.2.1 Seasonal Variation in Sulfate and Nitrate Readings

The SO_4 and NO_3 averages for 1982 are given by month in Table 4.1.

MONTH	SO_4	NO_3
JANUARY	2.13	0.75
FEBRUARY	3.62	1.26
MARCH	4.04	1.13
APRIL	4.83	0.78
MAY	6.50	1.20
JUNE	5.04	0.68
JULY	5.61	0.80
AUGUST	4.01	0.51
SEPTEMBER	3.45	0.59
OCTOBER	3.48	0.50
NOVEMBER	2.71	0.55
DECEMBER	2.61	0.48

Table 4.1: Sulfate and Nitrate readings by month.

The data were divided into 2 sets (April to September vs the other 6 months) to test for a seasonal variation. For SO_4, the average for the colder months was 2.99 mg/l while for the warmer months it was 4.75 mg/l. To test the statistical significance of this an analysis of variance was done (ANOVA routine in SAS User's Guide: Statistics 1982 Edition). The F test statistic had a value of 8.95 which gave a significance probability of 0.0001. Hence there is compelling evidence that the SO_4 measurements are higher in the summer than in the winter. For NO_3 on the other hand, the 2 averages are 0.79 mg/l for the colder months and 0.73 mg/l for the warmer months. The F statistic had a value of 0.45 in this case and a significance probability of 0.50 when testing the difference of means. For NO_3 then there was no evidence of a seasonal variation.

4.2.2 Relationships Among the Discrete Variables

Two way contingency tables were constructed among the discrete meteorological variables to examine their relative relationships. This was useful in order to strengthen our confidence in the quality of the meteorological analysis and as an aid in determining an independent set of predictors for the SO_4 and NO_3 measurements. A chi-square test was then performed on each table (SAS User's Guide: Basics 1982 Edition FREQ procedure pg 515). The significance probability of those tests are given in Table 4.2. The sparseness of data in parts of the tables in some cases may invalidate the chi-square test but it is still felt to be a useful start in looking for relationships.

As expected there was a very high degree of relationship among the meteorological variables. For example,it was reassuring to see that there is a strong relationship between cloud type and precipitation type. As a broad generalization, the trajectory ranges were the least correlated with the synoptic variables and clouds and weather variables. This table will be re-examined when considering the best variables to include in the statistical model.

4.2.3 Correlations Among Continuous Meteorological Variables

Tables 4.3 a) and b) display the correlation coefficient among the meteorological variables. It was obtained by applying the CORR procedure in the SAS User's Guide: Basics (1982 Edition pg 503). Also displayed are the significance probability of the correlation and the number of observations. Again here, there was a high correlation among the continuous meteorological variables. At a correlation coefficient above 0.5, the following groups of variables were highly related:

- surface temperature, surface dewpoint, precipitable water, totals index, 850 mb temperature, and rainrates of mm/15 min and mm/30 min.
- surface and 850 mb wind speed.
- cloud top and cloud thickness.
- rainfall rates and rainfall amounts.
- duration of precipitation and proportion of stations receiving precipitation.

These relations are to be expected and will be reconsidered in light of the particular variables which are most highly correlated with the SO_4 and NO_3 data.

4.2.4 Relationship Between SO_4 NO_3 and the Discrete Meteorological Variables

In an effort to identify those discrete meteorological variables which are important to the study of acid rain the following 2 tables were constructed.

SIGNIFICANCE PROBABILITY						
	SYNOPTIC TYPE	TRACK OF LOW	AIRMASS	TYPE OF PCPN	NATURE OF PCPN	CLOUD TYPE—
TRACK	0.0001					
AIRMASS	0.0001	0.0001				
850 24 HR SECTOR	0.0001	0.0001	0.0001	0.1118	0.0035	0.0001
850 24 HR RANGE	0.0001	0.0472	0.1543	0.5670	0.0811	0.5881
850 48 HR SECTOR	0.0001	0.0001	0.0001	0.1981	0.0343	0.2349
850 48 HR RANGE	0.0323	0.0001	0.0008	0.6106	0.9356	0.9487
SFC 24 HR SECTOR	0.0001	0.0001	0.0001	0.0085	0.0158	0.0270
SFC 24 HR RANGE	0.3511	0.2423	0.7923	0.7391	0.7352	0.8387
SFC 48 HR SECTOR	0.1997	0.0001	0.0559	0.0596	0.0565	0.0594
SFC 48 HR RANGE	0.2529	0.0737	0.5138	0.8504	0.0095	0.4181
TYPE OF PCPN	0.0001	0.3531	0.0554			
NATURE OF PCPN	0.1230	0.0001	0.0001	0.0001		
CLOUD TYPE	0.0004	0.0001	0.0035	0.0001	0.0001	
SFC WIND DIR	0.0001	0.0001	0.0007	0.0550	0.0040	0.1000
850 WIND DIR	0.0010	0.0001	0.0051	0.1500	0.0002	0.0020

Table 4.2: Significance probabilities among the meteorological variables using the chi-square test.

SAS

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	CHT	TAVG	TDAVG	WAV2	CAT34	CAT33	CAT16	THK	PW	TT
CHT	1.00000	0.10937	0.05642	-0.03899	0.14943	-0.02863	0.07942	-0.13950	0.14407	0.07346
CLD BASE HT	0.0000	0.1741	0.4842	0.6279	0.0769	0.7417	0.3886	0.1254	0.0883	0.3833
	157	156	156	157	143	135	123	122	141	143
TAVG	0.10937	1.00000	0.98521	-0.29260	0.93302	-0.12328	-0.15790	-0.13222	0.95873	0.72355
SFC TEMP	0.1741	0.0000	0.0001	0.0001	0.0001	0.1382	0.0738	0.1483	0.0001	0.0001
	156	168	166	168	154	146	130	121	152	154
TDAVG	0.05642	0.98521	1.00000	-0.34385	0.93965	-0.13519	-0.15527	-0.11831	0.86920	0.75655
SFC DEWPT	0.4842	0.0001	0.0000	0.0001	0.0001	0.0935	0.0777	0.1962	0.0001	0.0001
	156	166	166	168	154	146	130	121	152	154
WAV2	-0.03899	-0.29260	-0.34385	1.00000	-0.35261	0.50564	-0.02044	-0.00965	-0.32717	-0.34379
SFC WIND SPD	0.6279	0.0001	0.0001	0.0000	0.0001	0.0001	0.8168	0.9160	0.0001	0.0001
	157	168	168	169	155	147	131	122	153	155
CAT34	0.14943	0.93302	0.93965	-0.35261	1.00000	-0.18313	-0.10660	-0.06775	0.87190	0.73823
850 TEMP	0.0769	0.0001	0.0001	0.0001	0.0000	0.0213	0.2100	0.4584	0.0001	0.0001
	143	154	154	155	168	158	140	122	166	166
CAT33	-0.02863	-0.12328	-0.13519	0.50564	-0.18313	1.00000	-0.02013	0.01133	-0.25065	-0.19811
850 WIND SPD	0.7417	0.1382	0.0935	0.0001	0.0213	0.0000	0.8201	0.9052	0.0016	0.0126
	135	146	146	147	158	159	130	113	156	158
CAT16	0.07942	-0.15790	-0.15527	-0.02044	-0.10660	-0.02013	1.00000	0.97218	0.01294	0.05147
CLD TOP	0.3886	0.0738	0.0777	0.8168	0.2100	0.8201	0.0000	0.0001	0.8803	0.5459
	123	130	130	131	140	130	140	122	138	140
THK	-0.13950	-0.13222	-0.11831	-0.00965	-0.06775	0.01133	0.97218	1.00000	0.02775	0.06395
CLD DEPTH	0.1254	0.1483	0.1962	0.9160	0.4584	0.9052	0.0001	0.0000	0.7635	0.4641
	122	121	121	122	122	113	122	122	120	122
PW	0.14407	0.95873	0.86920	-0.32717	0.87190	-0.25065	0.01294	0.02775	1.00000	0.82810
PRECIP WATER	0.0883	0.0001	0.0001	0.0001	0.0001	0.0016	0.8803	0.7635	0.0000	0.0001
	141	152	152	153	166	156	138	120	165	166
TT	0.07346	0.72355	0.75655	-0.34379	0.73823	-0.19811	0.05147	0.06395	0.82810	1.00000
TOTAL TOTALS	0.3833	0.0001	0.0001	0.0001	0.0001	0.0126	0.5459	0.4641	0.0001	0.0000
	143	154	154	155	168	158	140	122	165	168

Table 4.3a. Correlation coefficients, significance probabilities, and number of observations among the continuous meteorological variables.

Table D1 (in Appendix D) gives the mean and standard deviation (SD) of the SO_4 and NO_3 measurements as a function of category for the discrete variables. Table E1 (found in Appendix E) displays the distribution of observations among the classes is given in frequency and percentage of observations for the top 30% of the SO_4 and NO_3 readings (above 4.55 mg/l and 0.90 mg/l respectively).

From Tables D1 and E1, some inferences regarding the meteorological factors which influence the SO_4 and NO_3 measurements can be drawn. In order for a factor to be considered important, the mean of the SO_4 or NO_3 readings for that category had to be the highest or second highest among the means for all categories of that variable. Also the frequency (in percentage) of that factor had to increase when considering the top 30% of the SO_4 or NO_3 readings as compared to the frequency in the whole data set.

With the above criteria, the following is a characterization of the high episodes of SO_4 . (Since the factors were considered separately no claim is made that all the factors happen simultaneously, although many of the fields mentioned are consistent with each other.)

	SO_4	NO_3
SYNOPTIC TYPE	stationary front	none
TRACK OF LOW	Colorado low	none
AIRMASS	mP mT	cA cmA mA
850 24 HR SECTOR	WNW WSW	WNW WSW
RANGE	200-400 km	200-400 km
48 hr SECTOR	WSW	WSW WNW
RANGE	<800 km	<800 km
SFC 24 HR SECTOR	ESE	SSE ENE
RANGE	none	none
48 HR SECTOR	SSW	WSW
RANGE	<200 km	<200 km
TYPE OF PCPN	convective	none
NATURE OF PCPC	rain	snow
CLOUD TYPE	stratus	stratus
SFC WIND DIR	SSW SSE	none
850 wind dir	WSW	none

Table 4.3c: Characterization of high SO_4 and NO_3 readings by the discrete meteorological variables.

In examining Table 4.3c, the trajectories associated with high SO_4 and NO_3 measurements were similar but for the other meteorological fields the important factors were dissimilar. Synoptic conditions had some effect on the high SO_4 readings but not on the high NO_3 readings. The airmasses associated with them were also different, mP and mT air with SO_4 and cA, cmA, and mA with NO_3. High SO_4 readings were associated with convective situations and rainfall while high

SO_4

	1982 F	1982 P>F	WARM MONTHS F	WARM MONTHS P>F	COLD MONTHS F	COLD MONTHS P>F
Synoptic type	1.35	0.24	1.16	0.33	1.88	0.09
Track of low	1.57	0.18	1.19	0.32	1.18	0.32
Airmass	2.90	0.003	1.81	0.09	1.42	0.20
850 mb 24 hr sector	1.78	0.11	1.92	0.10	2.09	0.09
range	2.17	0.03	0.44	0.84	0.76	0.64
48 hr sector	1.07	0.38	1.17	0.33	0.58	0.68
range	1.68	0.09	1.09	0.38	0.59	0.80
sfc 24 hr sector	1.75	0.10	2.29	0.04	1.47	0.19
range	1.65	0.13	0.51	0.77	1.34	0.25
48 hr sector	1.51	0.17	1.43	0.21	1.01	0.44
range	2.47	0.01	1.90	0.07	0.76	0.66
type of pcpn	5.18	0.006	5.92	0.02	0.27	0.76
nature of pcpn	8.29	0.0001	1.64	0.21	5.75	0.001
cloud type	1.82	0.09	0.86	0.53	5.36	0.0001
sfc wind dir	1.51	0.16	1.47	0.19	0.78	0.61
850 mb wind dir	1.06	0.39	1.39	0.23	0.21	0.97

NO_3

	1982 F	1982 P>F	WARM MONTHS F	WARM MONTHS P>F	COLD MONTHS F	COLD MONTHS P>F
Synoptic type	0.56	0.76	2.02	0.07	0.75	0.61
Track of low	0.43	0.79	0.90	0.47	0.83	0.51
Airmass	1.50	0.15	0.81	0.59	2.23	0.04
850 mb 24 hr sector	2.28	0.04	1.06	0.38	5.46	0.001
range	1.10	0.36	0.82	0.55	1.82	0.09
48 hr sector	1.99	0.07	1.30	0.27	1.94	0.11
range	0.69	0.73	0.79	0.61	0.73	0.68
sfc 24 hr sector	0.89	0.52	1.38	0.22	1.24	0.29
range	1.52	0.17	0.27	0.92	1.65	0.15
48 hr sector	0.82	0.57	0.73	0.65	1.06	0.40
range	1.78	0.07	2.29	0.03	0.77	0.66
type of pcpn	0.02	0.97	4.49	0.04	0.25	0.78
nature of pcpn	1.93	0.12	0.35	0.55	1.76	0.16
cloud type	3.69	0.001	1.12	0.36	2.88	0.01
sfc wind dir	1.25	0.27	1.27	0.28	0.84	0.56
850 mb wind dir			2.41	0.03	0.41	0.87

Table 4.4: An analysis of variance between SO_4 and NO_3 and the discrete variables. Given are the F statistic and the significance probability (P>F). Underlined values are those deemed significant enough to warrant further statistical testing.

NO_3 readings were associated with snow but had no relationship to the type of precipitation.

A one way analysis of variance was done between the SO_4 and NO_3 measurements and the discrete meteorological variables individually to assess the significance of the characterizations developed. Table 4.4 gives the F value and the significance probability for tests on the whole data set and tests dividing the data into cold and warm periods (procedure ANOVA in SAS User's Guide: Statistics 1982 Edition).

From Table 4.4 the following list of variables (Table 4.5) having a significance level below 0.10, by season, and will be tested in further statistical analysis.

SO_4		NO_3	
WARM MONTHS	COLD MONTHS	WARM MONTHS	COLD MONTHS
airmass	synoptic type	synoptic type	airmass
850 24 hr sector	850 24 hr sector	sfc 48 hr range	850 24 hr sector
sfc 24 hr sector	nature of pcpn	type of pcpn	850 24 hr range
sfc 48 hr range	cloud type	850 wind dir	cloud type
type of pcpn			

Table 4.5. Variables having a significance probability less than 0.10.

4.2.5. Relationship of SO_4 and NO_3 Measurements to the Continuous Meteorological Factors

Table 4.6 gives the correlation coefficients and significance probabilities between SO_4 and NO_3 and the continuous meteorological variables (procedure CORR in SAS User's Guide:Basics 1982 Edition). From this table, the variables with which the SO_4 had a correlation coefficient above 0.20 (either plus or minus) were surface temperature, precipitable water, duration of precipitation, and precipitation amount. For NO_3 the significant correlations were only with the rainfall variables, namely maximum rainrate in mm/hr, duration of precipitation, precipitation amount, maximum rainfall in 6 hr, and the proportion of stations receiving precipitation.

In a manner similar to the method of the previous section on discrete variables, the continuous meteorological variables behaviour for the high SO_4 and NO_3 readings were examined. Table 4.7 gives the averages and standard deviation for the continuous meteorological variables for the top 30% readings for SO_4 and NO_3.

Table 4.6: Correlation coefficients, significance probabilities, and number of observations between SO_4, NO_3, and the continuous meteorological variables.

CORRELATION COEFFICIENTS/PROB > R UNDER H0:RHO=0/NUMBER OF OBSERVATIONS

	SO_4	NO_3		SO_4	NO_3
CLOUD BASE HEIGHT	-0.033	-0.115	TOTAL TOTALS INDEX	0.174	-0.110
	0.69	0.16		0.03	0.16
	150	150		162	162
SURFACE TEMPERATURE	0.320	-0.128	RAINRATE (MM/15 MIN)	-0.021	-0.149
	0.0001	0.11		0.83	0.13
	161	161		106	106
SURFACE DEWPOINT	0.297	-0.151	RAINRATE (MM/30 MIN)	-0.046	-0.170
	0.0001	0.06		0.64	0.08
	161	161		106	106
SURFACE WIND SPEED	-0.090	-0.083	RAINRATE (MM/HR)	-0.101	-0.215
	0.25	0.30		0.30	0.03
	162	162		106	106
850 MB TEMPERATURE	0.337	-0.083	DURATION OF PRECIP	-0.295	-0.324
	0.0001	0.30		0.002	0.0008
	162	162		104	104
850 MB WIND SPEED	-0.081	-0.077	AVERAGE PRECIP RATE	-0.068	-0.100
	0.31	0.34		0.50	0.31
	153	153		104	104
CLOUD TOP HEIGHT	-0.131	-0.047	AMOUNT OF PRECIP	-0.213	-0.380
	0.13	0.59		0.005	0.0001
	134	134		174	174
CLOUD DEPTH	-0.061	-0.019	MAX 6 HR AMOUNT	-0.098	-0.333
	0.52	0.84		0.22	0.0001
	116	116		159	159
PRECIPITABLE WATER	0.289	-0.121	AREA OF PRECIP	-0.138	-0.328
	0.0002	0.12		0.07	0.0001
	160	160		176	176

	SO_4		NO_3	
	MEAN	SD	MEAN	SD
CLOUD BASE HEIGHT	603	421	609	482
SURFACE TEMPERATURE	10.4	8.7	2.6	10.3
SURFACE DEWPOINT	7.7	8.3	0.1	9.7
SURFACE WIND SPEED	8.7	4.8	8.4	5.0
850 MB TEMPERATURE	6.7	7.5	-0.1	10.1
850 MB WIND SPEED	25	11	25	11
CLOUD TOP	2973	1893	3417	1870
CLOUD THICKNESS	2493	1892	2932	1794
PRECIPITABLE WATER	22.9	11.8	16.3	11.4
TOTAL TOTALS	15.0	18.5	9.5	18.0
RAINRATE mm/15 min	2.1	1.7	1.5	0.9
mm/30 min	2.7	2.3	1.9	1.1
mm/hr	3.3	2.8	2.2	1.3
DURATION OF PCPN	5.7	3.3	5.5	3.7
AVERAGE RAINRATE mm/hr	1.0	0.9	0.9	0.8
AMOUNT OF PCPN	4.9	3.7	3.5	1.9
MAX 6 HR AMOUNT	3.5	3.2	2.3	1.9
% STNS WITH PCPN	0.61	0.27	0.58	0.23

Table 4.7: Averages and standard deviations (SD) of the continuous meteorological variables for the top 30% readings of the SO_4 and NO_3.

When the data are split by season (warm vs cold months) the significant parameters displayed some interesting variation. For example, airmass was significant for the SO_4 in the warm months while for the NO_3, it was significant in the cold months. This is in keeping with the previous statement that high SO_4 was associated with mP and mT air and high NO_3 with cA, cmA and mA air. The nature of the precipitation was significant for SO_4 in the winter when there were many examples of rain and snow, as opposed to the summer when only rain was seen so no useful discrimination would be possible. For the type of precipitation the reverse was true. The distinction between continuous and convective precipitation would be much less clear and more difficult to observe in winter. For NO_3 the synoptic type and the type of precipitation, which previously were found not to be related to the NO_3 readings, were significant in the warm months. During this time high NO_3 measurements were associated with warm fronts and stationary fronts, and with convective precipitation. During the cold months, high NO_3 readings are associated with other factors such that when viewed over the year, the synoptic type and precipitation type were not highly related to the NO_3 readings. The synoptic type was significantly related to SO_4 in winter. In this case there was a higher frequency of synoptic types for which the SO_4 readings were low (cold fronts, cold lows, occluded lows)

A comparison of Table 4.7 with Table C1 in Appendix C (the means and standard deviation for the whole data set) gives the variables with somewhat higher or lower averages in the top 30% of the SO_4 and NO_3 readings and is summarized in Table 4.8.

SO_4		NO_3	
HIGHER MEANS	LOWER MEANS	HIGHER MEANS	LOWER MEANS
surface temperature	cloud base height	none	cloud base height
surface dewpoint	surface wind speed		surface temperature
850 mb temperature	cloud top height		surface dewpoint
precipitable water	cloud thickness		surface wind speed
total totals index	duration of precipitation		850 mb temperature
	precipitation amount		precipitable water
	max 6 hr precipitation amount		total totals index
	proportion of stations with precipitation		all precipitation variables except average pcpn rate

Table 4.8. Variables which had means somewhat different from means in the whole data set when stratified into the top 30% of the SO_4 NO_3 measurements.

The general trend from Table 4.8 is that high SO_4 readings were associated with high temperatures and moisture and low precipitation events, low cloud bases, and low windspeeds. For NO_3 high readings were associated with low temperatures and moisture, low wind speeds, low cloud bases, and low precipitation events.

To further examine this, least squares estimates were used to construct linear regression models of SO_4 and NO_3 values with the continuous meteorological variables individually (procedure REG in SAS User's Guide: statistics 1982 Edition). The nature of the relationships and their significance can be better assessed. Table 4.9 gives the slope parameter b1 ($y=b_o+b_1*x$) and its significance probability for the whole year and the warm and cold months individually.

In Table 4.9, those variables which have the highest correlations with the SO_4 and NO_3 measurements are underlined and itemized in Table 4.10.

SO_4

	1982		WARM MONTHS		COLD MONTHS	
	b1	P>F	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.001	0.26	0.002	0.24	-0.001	0.15
SURFACE TEMPERATURE	0.13	0.02	0.08	0.39	-0.01	0.89
SURFACE DEWPOINT	0.14	0.02	0.08	0.44	0.01	0.91
SURFACE WIND SPEED	-0.11	0.14	-0.12	0.35	0.01	0.89
850 MB TEMPERATURE	0.14	0.02	0.13	0.15	-0.0002	0.99
850 MB WIND SPEED	-0.04	0.15	-0.01	0.86	0.01	0.65
CLOUD TOP	-0.0001	0.82	-0.0001	0.79	-0.00003	0.89
CLOUD THICKNESS	-0.0001	0.67	-0.0001	0.65	0.00002	0.90
PRECIPITABLE WATER	0.12	0.001	0.12	0.025	0.0004	0.99
TOTAL TOTALS	0.08	0.01	0.11	0.05	-0.001	0.98
RAINRATE mm/15 min	0.28	0.25	0.14	0.65	-0.26	0.51
mm/30 min	0.17	0.36	0.09	0.68	-0.26	0.33
mm/hr	0.07	0.65	0.05	0.80	-0.21	0.25
DURATION OF PCPN	-0.22	0.004	-0.22	0.08	-0.05	0.51
AVERAGE RAINRATE mm/hr	0.27	0.54	0.04	0.94	-1.24	0.13
AMOUNT OF PCPN	-0.14	0.03	-0.12	0.25	-0.11	0.05
MAX 6 HR AMOUNT	-0.14	0.17	-0.17	0.21	-0.12	0.23
% STNS WITH PCPN	-3.04	0.12	-2.95	0.34	-0.95	0.54

NO_3

	1982		warm months		cold months	
	b1	P>F	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.00001	0.95	0.0001	0.58	-0.003	0.09
SURFACE TEMPERATURE	0.004	0.57	-0.01	0.58	-0.01	0.32
SURFACE DEWPOINT	0.004	0.58	-0.01	0.46	-0.01	0.45
SURFACE WIND SPEED	-0.02	0.02	-0.02	0.13	-0.01	0.40
850 MB TEMPERATURE	0.001	0.87	-0.004	0.67	-0.01	0.23
850 MB WIND SPEED	-0.01	0.06	-0.003	0.68	-0.002	0.59
CLOUD TOP	-0.00001	0.71	-0.00001	0.80	-0.00001	0.70
CLOUD THICKNESS	-0.00001	0.70	-0.00001	0.74	-0.000003	0.93
PRECIPITABLE WATER	0.004	0.43	0.001	0.90	-0.01	0.28
TOTAL TOTALS	0.004	0.33	0.01	0.32	-0.01	0.28
RAINRATE mm/15 min	-0.001	0.95	-0.01	0.73	-0.01	0.11
mm/30 min	-0.01	0.77	-0.01	0.73	-0.09	0.06
mm/hr	-0.01	0.49	-0.01	0.66	-0.07	0.05
DURATION OF PCPN	-0.03	0.002	-0.03	0.02	-0.01	0.60
AVERAGE RAINRATE mm/hr	-0.02	0.76	-0.03	0.61	-0.03	0.04
AMOUNT OF PCPN	-0.02	0.01	-0.02	0.10	-0.02	0.06
MAX 6 HR AMOUNT	-0.03	0.03	-0.03	0.09	-0.04	0.05
% STNS WITH PCPN	-0.39	0.11	-0.30	0.39	-0.24	0.43

Table 4.9: Slope estimate and significance probability between SO_4, NO_3, and the continuous meteorological variables.

SO_4

1982	WARM MONTHS	COLD MONTHS
surface temperature	precipitable water	cloud base height
surface dewpoint	total totals	precipitation amount
850 mb temperature	duration of precipitation	
precipitable water		
total totals		
duration of precipitation		
precipitation amount		

NO_3

1982	WARM MONTHS	COLD MONTHS
surface wind speed	surface wind speed	precipitation amount
duration of precipitation	duration of precipitation	max 6 hr amount
precipitation amount	precipitation amount	cloud base height
max 6 hr amount	max 6 hr amount	

Table 4.10. Variables significantly correlated with SO_4 and NO_3.

For SO_4, splitting the data into warm and cold months reduces the number of significant variables. In essence the splitting removes the information which was contained in many of the correlations, for example surface and 850 mb temperature, surface dewpoint. For NO_3, except for surface wind speed, which itself was very marginal, only precipitation variables show significant correlations.

5. Statistical Model

5.1 Southwest Region

Using the ideas and results of the previous section, a statistical model can be developed to predict SO_4 and NO_3 values. A separate model can be developed for the warm and cold seasons. The technique to be used is the analysis of covariance (ANCOVA) where 2 discrete and 2 continuous meteorological variables will be used (procedure GLM in SAS User's Guide: Statistics 1982, Edition pg 140). The choice of 2 discrete variables was arbitrary but done in order that a sufficient number of cases would be present for each combination of the discrete variables. For the continuous variables, the correlations among the meteorological variables and between the SO_4 and NO_3 and the meteorological variables indicated that 2 continuous variables would be sufficient. In theory every conceivable combination of meteorological variables could be tested. But the findings of the previous section have provided the basis for eliminating many of the meteorological variables from consideration and resulted in a more manageable set of variables for statistical modelling tests.

Based on Tables 4.5 and 4.10 the following ANCOVA analyses were carried out. Table 5.1 gives the 4 variables plus the interaction term between the 2 discrete variables, their individual F value and significance probability (P>F), the F value for the set of variables, its significance probability, the proportion of the variance of the dependent variable (SO_4 or NO_3) explained by the model (R), and the mean squared error of the difference between the model's predictions and observations (E^2). The sum of the errors would by design be 0. The optimal situation would be low significance probabilities, high R, and low E^2.

Table 5.1: Results of the ANCOVA.

WARM MONTHS

SO_4

VARIABLE	F	P>F	F	P>F	R	E^2
type of pcpn	3.78	0.06	1.02	0.46	0.27	7.62
airmass	1.13	0.37				
interaction	0.38	0.82				
precipitable water	0.09	0.77				
duration of pcpn	0.98	0.33				
sfc 48 hr range	1.18	0.35	0.57	0.92	0.35	6.79
airmass	0.66	0.70				
interaction	0.18	0.99				
precipitable water	0.14	0.71				
duration of pcpn	0.09	0.77				

cont'd

Table 5.1 cont'd

850 24 hr sector	2.21	0.07	1.44	0.19	0.29	7.62
type of pcpn	2.10	0.16				
interaction	0.69	0.57				
precipitable water	0.05	0.82				
duration of pcpn	0.60	0.44				
sfc 48 hr range	1.05	0.42	0.85	0.62	0.27	8.12
type of pcpn	2.31	0.14				
interaction	0.48	0.75				
precipitable water	0.24	0.62				
duration of pcpn	0.02	0.88				
type of pcpn	3.78	0.06	1.02	0.46	0.28	7.62
airmass	1.13	0.37				
interaction	0.38	0.82				
precipitable water	0.09	0.77				
duration of pcpn	0.98	0.33				
type of pcpn	4.97	0.03	2.69	0.01	0.47	5.96
sfc 24 hr sector	3.13	0.01				
interaction	2.32	0.09				
precipitable water	0.68	0.41				
duration of pcpn	0.82	0.37				
	NO_3					
type of pcpn	2.51	0.12	1.07	0.42	0.29	0.21
sfc 48 hr range	0.87	0.54				
interaction	0.35	0.84				
duration of pcpn	1.43	0.24				
sfc wind speed	3.48	0.07				
synoptic type	2.11	0.08	1.43	0.17	0.56	0.14
sfc 48 hr range	1.16	0.36				
interaction	1.12	0.38				
duration of pcpn	3.10	0.09				
amount of pcpn	1.65	0.21				
type of pcpn	2.53	0.12	1.10	0.39	0.30	0.21
sfc 48 hr range	0.88	0.53				
interaction	0.36	0.84	0.30			
duration of pcpn	1.44	0.24				
amount of pcpn	3.80	0.06				

cont'd

Table 5.1 cont'd

COLD MONTHS

SO_4

nature of pcpn	8.02	0.0002	4.81	0.0001	0.59	2.19
synoptic type	2.59	0.03				
interaction	3.65	0.001				
cloud base height	5.11	0.03				
amount of pcpn	18.63	0.0001				
cloud type	7.73	0.0001	3.91	0.0001	0.62	1.99
synoptic type	1.63	0.15				
interaction	2.54	0.01				
cloud base height	4.28	0.04				
amount of pcpn	10.72	0.002				
cloud type	9.15	0.0001	7.22	0.0001	0.64	1.93
850 24 hr sector	6.87	0.0005				
interaction	5.50	0.0001				
cloud base height	5.18	0.03				
amount of pcpn	9.09	0.004				

NO_3

cloud type	3.65	0.004	2.17	0.01	0.56	0.20
850 24 hr range	1.06	0.41				
interaction	1.29	0.24				
cloud base height	0.48	0.49				
amount of pcpn	17.90	0.0001				
cloud type	3.75	0.003	2.63	0.001	0.52	0.22
airmass	2.06	0.06				
interaction	1.36	0.22				
cloud base height	0.07	0.79				
amount of pcpn	15.13	0.0003				
850 24 hr range	1.37	0.23	1.56	0.07	0.52	0.22
airmass	1.89	0.09				
interaction	1.08	0.40				
cloud base height	1.41	0.24				
amount of pcpn	9.41	0.003				
cloud type	5.37	0.0001	6.96	0.0001	0.64	0.17
850 24 hr sector	12.32	0.0001				
interaction	6.05	0.0001				
cloud base height	1.09	0.30				
amount of pcpn	11.76	0.001				

From Table 5.1, the variables which comprised the best set of variables, by time of year, were the following (their values are underlined in Table 5.1):

WARM MONTHS	for SO_4	type of precipitation surface 24 hr sector precipitable water duration of precipitation
	for NO_3	synoptic type surface 48 hr range duration of precipitation amount of precipitation
COLD MONTHS	for both SO_4 AND NO_3	cloud type 850 24 hr sector cloud base height amount of precipitation

The combinations of discrete variables which performed the best invariably had very strong interaction terms. Appendix F, which contains contingency tables for the pairs of discrete variables which were chosen (Tables F1 to F3), shows the relationship between the different categories of the 3 pairs of discrete variables. Referring back to Table 4.2, the type of precipitation was highly related to surface 24 hr sector as was cloud type to 850 mb 24 hr sector. Synoptic type and surface 48 hr range on the other hand were not so highly related. Also given in Appendix A are the scatter plots of SO_4 or NO_3 versus the continuous meteorological variables chosen (Figures F1 to F8). They show the nature of the relationship, as summarized in Table 4.9, and establish that there were not some extreme points which controlled the regression.

Summarizing, the situations which will characterize high acidic measurements are the following. For SO_4 in the warm months, convective situations with the 24 hr surface trajectory from the ESE and precipitable water high and duration of the precipitation event low were the aspects of the 4 chosen variables associated with high SO_4 readings. For the cold months, for both SO_4 and NO_3, they are 850 mb 24 hr trajectories from the WNW with overcast stratus and low cloud bases and low precipitation amounts. For NO_3 in the warm season, warm or stationary fronts with surface 48 hr trajectories originating less than 200 km away giving low precipitation duration and amount were the aspects of the 4 chosen meteorological variables associated with high N_{O3} readings.

The preceding judgments are somewhat open to conjecture. However it was reassuring to note that generally there was little departure from normality for the errors in prediction. But the test of the model on an independent data set, e.g. 1983, will ultimately determine the model's worth in trying to be able to estimate annual deposition based on a limited set of Eulerian model runs and a specified time period of observed deposition and meteorological data.

5.2. Northwest Region

In order to see how conditions vary, an analysis of variance was done between the SO_4 and NO_3 measurements and the meteorological variables for the northwest region, the one most dissimilar from the southwest region. Table 5.2 gives the results of the analysis of variance (in SAS User's Guide: Statistics 1982 Edition ANOVA procedure), again split into warm and cold months (April to September vs the rest).

Table 5.2: Analysis of variance for the northwest region.

SO_4

	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
Synoptic type	0.75	0.61	2.44	0.04
Track of low	0.17	0.68	0.73	0.57
Airmass	2.17	0.04	4.03	0.002
850 mb 24 hr sector	2.63	0.02	0.76	0.63
range	0.70	0.65	1.97	0.08
48 hr sector	3.86	0.002	1.32	0.27
range	1.26	0.28	0.84	0.58
sfc 24 hr sector	0.77	0.62	0.95	0.48
range	1.97	0.09	2.81	0.02
48 hr sector	3.03	0.008	0.88	0.53
range	3.41	0.004	0.23	0.98
type of pcpn	2.49	0.12	0.59	0.45
nature of pcpn	2.09	0.13	0.96	0.39
cloud type	2.07	0.08	0.26	0.93
sfc wind dir	1.00	0.44	0.81	0.60
850 mb wind dir	0.39	0.88	0.92	0.50

cont'd

Table 5.2 cont'd

	NO_3			
	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
Synoptic type	0.81	0.56	3.64	0.004
Track of low	0.06	0.81	0.49	0.74
Airmass	3.03	0.005	2.43	0.04
850 mb 24 hr sector	1.82	0.11	2.23	0.05
range	0.36	0.90	0.89	0.52
48 hr sector	1.92	0.09	4.46	0.001
range	0.98	0.46	0.57	0.80
sfc 24 hr sector	1.64	0.14	2.00	0.07
range	2.69	0.03	1.40	0.23
48 hr sector	3.19	0.006	1.04	0.42
range	1.56	0.16	0.48	0.84
type of pcpn	0.69	0.41	0.06	0.80
nature of pcpn	2.03	0.14	0.35	0.70
cloud type	1.12	0.36	0.46	0.80
sfc wind dir	1.05	0.40	0.88	0.53
850 mb wind dir	0.66	0.68	1.14	0.36

Also, linear correlations between SO_4 and NO_3 readings and the continuous meteorological variables were done by time of year for the northwest region (procedure REG in SAS User's Guide: Statistics 1982 Edition). The slope parameter of the regression along with the significance probability of the relationship is given in Table 5.3.

Table 5.3: Slope estimate and significance probability between SO_4 NO_3 and the continuous meteorological variables.

SO_4

	WARM MONTHS		COLD MONTHS	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	-0.0009	0.02	-0.0003	0.46
SURFACE TEMPERATURE	-0.64	0.01	0.019	0.18
SURFACE DEWPOINT	-0.067	0.01	0.018	0.17
SURFACE WIND SPEED	0.024	0.54	-0.021	0.53
850 MB TEMPERATURE	-0.034	0.13	0.02	0.26
850 MB WIND SPEED	0.02	0.22	0.013	0.39
CLOUD TOP	-0.0001	0.40	0.0001	0.52
CLOUD THICKNESS	-0.00003	0.77	0.0002	0.26
PRECIPITABLE WATER	-0.032	0.08	0.036	0.19
TOTAL TOTALS	-0.011	0.34	0.008	0.50
RAINRATE mm/15 min	-0.017	0.72	-0.039	0.83
mm/30 min	-0.016	0.67	-0.03	0.81
mm/hr	-0.012	0.69	-0.039	0.65
DURATION OF PCPN	-0.014	0.52	0.012	0.59
AVERAGE RAINRATE mm/hr	0.026	0.81	-0.024	0.92
AMOUNT OF PCPN	-0.032	0.14	-0.026	0.38
MAX 6 HR AMOUNT	-0.023	0.31	-0.041	0.40
% STNS WITH PCPN	-1.004	0.03	-0.452	0.38

NO_3

	WARM MONTHS		COLD MONTHS	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	-0.0001	0.13	-0.000002	0.98
SURFACE TEMPERATURE	-0.009	0.01	-0.003	0.32
SURFACE DEWPOINT	-0.009	0.01	-0.003	0.32
SURFACE WIND SPEED	0.0024	0.67	-0.009	0.24
850 MB TEMPERATURE	-0.003	0.40	-0.004	0.37
850 MB WIND SPEED	0.001	0.54	0.002	0.62
CLOUD TOP	-0.000002	0.90	-0.000003	0.92
CLOUD THICKNESS	0.00002	0.90	0.00001	0.74
PRECIPITABLE WATER	-0.004	0.16	-0.007	0.24
TOTAL TOTALS	-0.001	0.47	-0.002	0.43
RAINRATE mm/15 min	0.001	0.91	-0.012	0.71
mm/30 min	0.00013	0.98	-0.013	0.57
mm/hr	-0.007	0.86	-0.012	0.43
DURATION OF PCPN	-0.002	0.52	-0.006	0.15
AVERAGE RAINRATE mm/hr	0.008	0.54	-0.043	0.40
AMOUNT OF PCPN	-0.003	0.28	-0.009	0.10
MAX 6 HR AMOUNT	-0.002	0.40	-0.014	0.13
% STNS WITH PCPN	-0.158	0.02	-0.133	0.21

Using Tables 5.2 and 5.3, the variables which were deemed to show enough promise in their relation to SO_4 and NO_3 (and whose significance probabilities are underlined) to warrant further testing in ANCOVA are given in Table 5.4. The significance probabilities for the continuous variables in the cold season were quite high and made selection of any variables then somewhat dubious.

SO_4		NO_3	
WARM MONTHS	COLD MONTHS	WARM MONTHS	COLD MONTHS
airmass	airmass	airmass	airmass
850 48 hr sector	synoptic type	sfc 48 hr sector	850 48 hr sector
sfc 48 hr range	sfc 24 hr range		
cloud type			
cloud base height	surface temp.	surface temp.	amount of pcpn
surface temperature	precipitable water	stations with pcpn	

Table 5.4: Meteorological variables significantly related to SO_4 and NO_3.

For the variables listed in Table 5.4 the ANCOVA was run. The results are given in Table 5.5.

Table 5.5: Results of ANCOVA for northwest region.

WARM MONTHS

SO_4

VARIABLE	F	P>F	F	P>F	R	E^2
sfc 48 hr range	10.18	0.0001	5.27	0.0001	0.83	0.39
airmass	6.89	0.0001				
interaction	1.93	0.072				
cloud base height	0.09	0.772				
sfc temperature	9.75	0.004				
sfc 48 hr range	3.98	0.004	1.43	0.17	0.51	1.09
cloud type	0.65	0.662				
interaction	0.50	0.892				
cloud base height	0.34	0.563				
sfc temperature	1.36	0.25				
airmass	2.73	0.023	1.86	0.04	0.58	1.00
850 48 hr sector	3.78	0.005				
interaction	0.54	0.864				
cloud base height	0.07	0.792				
sfc temperature	0.61	0.441				

cont'd

Table 5.5 cont'd

cloud type	3.04	0.020	2.46	0.007	0.56	1.03
850 48 hr sector	3.19	0.012				
interaction	1.00	0.453				
cloud base height	0.11	0.742				
sfc temperature	9.26	0.004				
airmass	3.43	0.005	2.78	0.002	0.62	0.84
cloud type	3.82	0.0061				
interaction	2.21	0.032				
cloud base height	0.16	0.693				
sfc temperature	1.93	0.172				

NO_3

airmass	7.60	0.001	3.67	0.0002	0.81	0.01
sfc 48 hr sector	3.45	0.007				
interaction	2.45	0.012				
stns with pcpn	0.00	0.992				
sfc temperature	1.83	0.186				

COLD MONTHS

SO_4

VARIABLE	F	P>F	F	P>F	R	E^2
airmass	2.55	0.048	1.50	0.17	0.61	0.66
sfc 24 hr range	1.74	0.158				
interaction	0.85	0.585				
sfc temperature	1.04	0.318				
precipitable water	0.79	0.382				
sfc 24 hr range	2.67	0.041	1.53	0.16	0.61	0.65
synoptic type	1.30	0.297				
interaction	0.91	0.539				
sfc temperature	0.03	0.866				
precipitable water	3.69	0.067				

NO_3

airmass	3.49	0.010	2.53	0.01	0.65	0.01
850 48 hr sector	2.05	0.091				
interaction	2.36	0.044				
pcpn amount	1.13	0.296				

From Table 5.5 the set of meteorological variables which provide the best statistical model (and are underlined) are the following:

SO_4		NO_3	
WARM MONTHS	COLD MONTHS	WARM MONTHS	COLD MONTHS
airmass	sfc 24 hr range	airmass	airmass
sfc 48 hr range	synoptic type	sfc 48 hr sector	850 48 hr sector
cloud base height	sfc temperature	sfc temperature	amount of pcpn
sfc temperature	precipitable water	stations with pcpn	

A comparison of this list of variables with the list composed in the southwest region analysis reveals that for the discrete variables, airmass was a more significant variable in the northwest region while precipitation type and cloud type were more significant in the southwest region. Both areas relied on a trajectory variable as a significant variable. For the continuous variables, precipitation variables were more predominant in the southwest (which is not surprising considered the differences in the rain gauge networks) while temperatures were more prominant in the northwest.

It is interesting to compare these results with those that would have been obtained if the significant variables from the southwest region were used in the ANCOVA analysis for the northwest region. In this case the results of the ANCOVA are shown in Table 5.6.

Table 5.6: ANCOVA results using the same variables as for the analysis in the southwest region.

VARIABLE	F	P>F	F	P>F	R	E^2
WARM MONTHS						
	SO_4					
type of pcpn	4.97	0.03	1.60	0.13	0.37	0.92
sfc 24 hr sector	0.89	0.52				
interaction	3.17	0.04				
precipitable water	0.00	0.94				
duration of pcpn	0.11	0.74				
	NO_3					
synoptic type	2.16	0.75	2.42	0.01	0.69	0.01
sfc 48 hr range	5.08	0.0007				
interaction	1.44	0.198				
duration of pcpn	0.01	0.91				
amount of pcpn	0.36	0.55				

cont'd

Table 5.6 cont'd

COLD MONTHS

	SO_4					
cloud type	0.25 0.94		0.60	0.88	0.29	1.12
850 24 hr sector	0.60 0.75					
interaction	1.07 0.40					
cloud base height	0.11 0.74					
amount of pcpn	0.03 0.87					
	NO_3					
cloud type	0.48 0.79		1.07	0.43	0.42	0.03
850 24 hr sector	1.53 0.20					
interaction	1.29 0.29					
cloud base height	0.20 0.66					
amount of pcpn	0.28 0.60					

A comparison of Tables 5.1, 5.4, and 5.6 shows that the variables picked out in the analysis of the southwest region did not perform nearly so well in the northwest when compared to the ANCOVA results of these variables in the southwest or when compared to the ANCOVA results for the northwest when the variables used were determined by the analysis of the northwest data (Table 5.7). In general the ANCOVA analyses for the 2 regions were comparable for the cold months (when the variables used in the northwest analysis were chosen from the analysis of the northwest data) but for the warm months the ANCOVA analysis was better in the northwest than the southwest regions in that it had smaller errors and explained more of the SO_4 and NO_3 variance. This effect would largely be attributable to the smaller range and means of the SO_4 and NO_3 in the northwest in the warm months.

R (from ANCOVA)

		SW	NW(SW)	NW
WARM MONTHS	SO_4	0.47	0.37	0.83
	NO_3	0.56	0.69	0.81
COLD MONTHS	SO_4	0.64	0.29	0.61
	NO_3	0.64	0.42	0.65

Table 5.7: A comparison among the ANCOVA analyses for the southwest region (SW), the northwest region when the variables used in the analysis were the same as those used in the southwest analysis (NW(SW)), and the northwest region when the variables used were determined by an analysis of the northwest region (NW). Displayed is the amount of variance in the dependent variable (SO_4 or NO_3) explained by the ANCOVA analysis (R).

However, the net result is that the variables found to be significant in one region are not necessarily the best in another region. This should be neither surprising nor disturbing. The quality of the meteorological data in the 2 regions is not the same. The southwest region has a much more dense rain gauge network, the APIOS stations are more closely grouped, and the main hourly site (London) is well located amongst the 4 stations. This is not the case in the northwest sector. Secondly, the meteorological conditions are significantly different. As was previously stated, fronts play a larger role in the southwest region and occluded systems in the northwest. Consequently the type of airmass was a more significant factor in the northwest while cloud type and precipitation type were bigger factors in the southwest. The result then is that each region should be considered on its own, with its meteorological peculiarities and data base taken into account. Thus each region would have its own tailored statistical model. However this is not to say that the processes involved in acid rain are different in each region. As was shown for the southwest region, the different meteorological variables were highly related. The fact that one may be more appropriate in a particular region is due to the uniqueness of that region to the meteorological conditions and the non-uniform degree of the data between regions. A second year of data would help further clarify this point.

5.3 Central Region

An analysis of variance was performed between the discrete meteorological variables and the SO_4 and NO_3 measurements, in a manner similar to the northwest region. The results are given in Table 5.8, where the underlined variables are the ones which were retained for the covariance analysis. In this regard, the variables which were kept were those which had low significance probabilities and most consistent with the previous analyses. Thus, the selection process was more stringent here than previously.

Table 5.9 contains the results of the linear regression between the continuous meteorological variables and the SO_4 and NO_3 readings. Here also, the desire to have consistency with the variables chosen in the first two regions studied strongly affected the choice of variables to be used in the ANCOVA analysis. In addition, cloud top and cloud thickness were thought to have too many missing values to be useful.

SO_4

	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
Synoptic type	1.01	0.43	1.44	0.21
Track of low	1.48	0.22	2.75	0.02
Airmass	1.84	0.09	2.56	0.02
850 mb 24 hr sector	1.93	0.09	0.52	0.67
range	2.35	0.04	0.62	0.78
48 hr sector	3.87	0.004	1.86	0.13
range	2.22	0.03	1.23	0.28
sfc 24 hr sector	3.21	0.005	2.06	0.06
range	1.86	0.11	0.62	0.71
48 hr sector	3.51	0.003	7.56	0.0001
range	0.96	0.47	0.50	0.85
type of pcpn	3.71	0.06	0.15	0.86
nature of pcpn	1.01	0.37	1.39	0.25
cloud type	0.53	0.75	0.45	0.87
sfc wind dir	2.69	0.01	1.44	0.19
850 mb wind dir	1.53	0.18	0.66	0.68

NO_3

	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
Synoptic type	1.33	0.26	1.74	0.12
Track of low	0.35	0.84	0.83	0.53
Airmass	1.67	0.13	0.70	0.67
850 mb 24 hr sector	1.91	0.09	1.26	0.29
range	2.22	0.05	1.19	0.31
48 hr sector	3.05	0.01	2.22	0.07
range	2.31	0.02	1.00	0.45
sfc 24 hr sector	3.94	0.001	3.05	0.007
range	1.61	0.17	0.94	0.47
48 hr sector	2.92	0.01	4.26	0.001
range	0.62	0.74	0.75	0.65
type of pcpn	2.33	0.13	0.43	0.65
nature of pcpn	1.45	0.24	2.32	0.06
cloud type	0.50	0.78	0.92	0.50
sfc wind dir	1.53	0.16	1.11	0.36
850 mb wind dir	2.40	0.04	1.00	0.43

Table 5.8: Analysis of Variance of the discrete variables for Central Region

	SO_4 WARM MONTHS		COLD MONTHS	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.0001	0.85	0.0006	0.24
SURFACE TEMPERATURE	0.05	0.29	0.09	0.002
SURFACE DEWPOINT	0.002	0.97	0.08	0.003
SURFACE WIND SPEED	-0.011	0.87	0.015	0.76
850 MB TEMPERATURE	0.004	0.93	0.130	0.001
850 MB WIND SPEED	0.024	0.42	-0.016	0.59
CLOUD TOP	-0.0002	0.40	-0.0004	0.01
CLOUD THICKNESS	-0.0001	0.52	-0.0003	0.05
PRECIPITABLE WATER	0.02	0.53	0.100	0.02
TOTAL TOTALS	-0.005	0.82	0.019	0.42
RAINRATE mm/15 min	0.201	0.38	1.175	0.26
mm/30 min	0.098	0.54	0.795	0.28
mm/hr	0.034	0.79	0.346	0.54
DURATION OF PCPN	-0.104	0.09	-0.262	0.06
AVERAGE RAINRATE mm/hr	0.338	0.44	3.959	0.02
AMOUNT OF PCPN	-0.024	0.70	-0.009	0.91
MAX 6 HR AMOUNT	0.020	0.74	0.121	0.29
% STNS WITH PCPN	0.504	0.66	-0.971	0.52

	NO_3 WARM MONTHS		COLD MONTHS	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.00004	0.72	0.0003	0.01
SURFACE TEMPERATURE	-0.002	0.82	-0.012	0.09
SURFACE DEWPOINT	-0.003	0.69	-0.012	0.06
SURFACE WIND SPEED	-0.011	0.33	-0.004	0.73
850 MB TEMPERATURE	-0.004	0.55	-0.003	0.69
850 MB WIND SPEED	0.001	0.84	-0.005	0.34
CLOUD TOP	-0.00001	0.71	-0.0001	0.05
CLOUD THICKNESS	-0.00001	0.76	-0.0001	0.05
PRECIPITABLE WATER	-0.003	0.59	-0.006	0.42
TOTAL TOTALS	-0.001	0.86	-0.003	0.53
RAINRATE mm/15 min	0.002	0.97	0.044	0.76
mm/30 min	-0.005	0.85	0.029	0.78
mm/hr	-0.014	0.49	-0.004	0.96
DURATION OF PCPN	-0.016	0.09	-0.037	0.05
AVERAGE RAINRATE mm/hr	0.004	0.95	0.389	0.11
AMOUNT OF PCPN	-0.008	0.37	-0.045	0.002
MAX 6 HR AMOUNT	-0.007	0.50	-0.046	0.02
% STNS WITH PCPN	0.16	0.37	-0.52	0.05

Table 5.9: Linear Regressions between the continuous meteorological variables and the SO_4 and NO_3 measurements for the Central Region

For the variables underlined in Tables 5.8 and 5.9 the ANCOVA routine was run (Table 5.10).

Table 5.10: Results of the ANCOVA for the Central Region.

VARIABLE	F	P>F	F	P>F	R	E^2
		WARM MONTHS				
		SO_4				
type of precipitation	5.25	0.026	2.39	0.100	0.44	3.94
sfc 48 hr sector	4.12	0.001				
interaction	0.07	0.998				
duration of precipitation	3.57	0.065				
sfc temperature	0.24	0.627				
airmass	1.58	0.166	1.54	0.100	0.50	3.77
sfc 48 hr sector	2.86	0.015				
interaction	0.81	0.643				
duration of pcpn	2.30	0.136				
sfc temperature	0.00	0.990				
		NO_3				
sfc 48 hr sector	2.80	0.017	1.21	0.284	0.44	0.09
airmass	0.50	0.827				
interaction	0.54	0.864				
duration of pcpn	3.59	0.065				
sfc wind speed	0.02	0.902				
sfc 48 hr sector	6.49	0.0001	4.44	0.0001	0.80	0.03
850 wind direction	7.93	0.0001				
interaction	2.74	0.0089				
duration of pcpn	0.64	0.4285				
sfc wind speed	0.08	0.7747				

cont'd

Table 5.10 cont'd

COLD MONTHS

SO_4

airmass	5.11	0.001	4.86	0.0001	0.79	1.50
sfc 48 hr sector	4.59	0.001				
interaction	5.00	0.0001				
sfc temperature	2.72	0.107				
track of low	3.96	0.005	3.30	0.0001	0.67	2.35
sfc 48 hr sector	4.34	0.001				
interaction	2.39	0.010				
sfc temperature	7.12	0.011				

NO_3

sfc 48 hr sector	6.65	0.0001	6.32	0.0001	0.70	0.11
nature of pcpn	3.27	0.019				
interaction	10.3	0.0001				
cloud base height	1.58	0.214				
pcpn amount	5.12	0.028				
sfc 24 hr sector	2.76	0.020	2.08	0.022	0.37	0.21
nature of pcpn	1.38	0.253				
interaction	0.59	0.673				
cloud base height	0.75	0.389				
pcpn amount	8.13	0.006				

From the ANCOVA analyses, the variables in Table 5.11 whose ANCOVA results are underlined in Table 5.10 provided the best set in explaining the variation in SO_4 and NO_3. Here again, the set of variables chosen for the SO_4 for the warm months was done with a view to being consistent with the results from the southwest region.

SO_4		NO_3	
WARM MONTHS	COLD MONTHS	WARM MONTHS	COLD MONTHS
precipitation type	airmass	sfc 48 hr sector	sfc 48 hr sector
sfc 48 hr sector	sfc 48 hr sector	850 wind direction	nature of pcpn
pcpn duration	sfc temperature	pcpn duration	cloud base height
sfc temperature		sfc wind speed	pcpn amount

Table 5.11: Variables which comprised the best set for the central region, as deduced from the ANCOVA.

Table 5.12 contains the results of the ANCOVA when the variables which were significant in the southwest analysis were used.

VARIABLE	F	P>F	F	P>F	R	E^2
		WARM MONTHS				
		SO_4				
type of pcpn	4.92	0.032	1.67	0.092	0.39	4.23
sfc 24 hr sector	2.59	0.026				
interaction	0.42	0.860				
precipitable water	0.06	0.807				
duration of pcpn	1.08	0.304				
		NO_3				
synoptic type	1.99	0.090	1.07	0.412	0.48	0.09
sfc 48 hr range	0.48	0.841				
interaction	1.07	0.413				
duration of pcpn	0.74	0.395				
pcpn amount	0.11	0.743				
		COLD MONTHS				
		SO_4				
cloud type	0.56	0.787	1.64	0.076	0.31	4.37
850 24 hr sector	1.11	0.351				
interaction	2.87	0.015				
cloud base height	3.75	0.057				
pcpn amount	1.31	0.257				
		NO_3				
cloud type	1.11	0.369	1.84	0.039	0.34	0.21
850 24 hr sector	2.27	0.087				
interaction	1.65	0.149				
cloud base height	2.23	0.141				
pcpn amount	6.42	0.014				

Table 5.12: ANCOVA using the variables from the southwest analysis.

Comparing Table 5.12 with the results of the best set of variables in Table 5.11 reveals that the amount of variance explained by using the variables that were best in the southwest region was much less than when variables determined by the analysis of the Central region were used. For SO_4, 0.39 vs 0.44 and 0.79 vs 0.31 were the differences in variance explained in the warm months and cold months respectively. For NO_3, the corresponding numbers are 0.48 vs 0.80 and 0.34 vs 0.70 (Table 5.13).

		R (from ANCOVA)	
		CE	CE(SW)
WARM MONTHS	SO_4	0.44	0.39
	NO_3	0.80	0.48
COLD MONTHS	SO_4	0.79	0.31
	NO_3	0.70	0.34

Table 5.13: The amount of variance of the dependent variable (SO_4 or NO_3) explained by the ANCOVA analysis (R) for the central region when the variables were selected from by an analysis of the central region (CE) and when the variables used in the analysis were the same as those used in the southwest analysis (CE(SW)).

5.4 Southeast Region

Table 5.14 contains the results of the analysis of variance and Table 5.15 the results of the linear regression of the appropriate variables for the southeast region. The values underlined indicate those variables which will be used in the ANCOVA.

	SO_4			
	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
Synoptic type	1.20	0.32	0.26	0.95
Track of low	2.64	0.04	1.46	0.22
Airmass	1.49	0.19	1.47	0.19
850 mb 24 hr sector	3.07	0.02	1.00	0.41
range	1.47	0.21	0.92	0.51
48 hr sector	4.28	0.001	0.56	0.76
range	0.96	0.48	0.49	0.89
sfc 24 hr sector	2.03	0.07	1.57	0.16
range	0.62	0.68	0.86	0.53
48 hr sector	3.15	0.008	1.56	0.16
range	0.63	0.73	0.94	0.49
type of pcpn	0.17	0.68	2.17	0.14
nature of pcpn	1.64	0.21	3.90	0.01
cloud type	1.48	0.20	0.26	0.97
sfc wind dir	1.87	0.09	1.13	0.36
850 mb wind dir	2.51	0.05	0.75	0.56

	NO_3			
	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
Synoptic type	1.11	0.37	0.64	0.70
Track of low	1.43	0.24	0.94	0.44
Airmass	2.13	0.06	0.50	0.83
850 mb 24 hr sector	1.89	0.11	2.25	0.07
range	1.80	0.12	1.19	0.32
48 hr sector	2.88	0.02	1.26	0.29
range	1.73	0.11	0.99	0.46
sfc 24 hr sector	1.59	0.16	1.29	0.27
range	1.01	0.42	1.71	0.13
48 hr sector	1.95	0.08	0.50	0.83
range	0.51	0.82	0.78	0.63
type of pcpn	0.01	0.92	1.11	0.30
nature of pcpn	6.45	0.01	4.67	0.01
cloud type	1.35	0.25	0.71	0.67
sfc wind dir	2.72	0.02	0.94	0.48
850 mb wind dir	2.27	0.07	0.39	0.82

Table 5.14: Analysis of Variance of the discrete variables for Southeast Region

SO_4	WARM MONTHS		COLD MONTHS	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.001	0.33	0.001	0.44
SURFACE TEMPERATURE	-0.012	0.86	0.086	0.003
SURFACE DEWPOINT	-0.002	0.98	0.83	0.003
SURFACE WIND SPEED	-0.152	0.05	-0.049	0.24
850 MB TEMPERATURE	0.024	0.71	0.053	0.09
850 MB WIND SPEED	0.023	0.37	-0.026	0.14
CLOUD TOP	-0.0003	0.14	-0.0002	0.09
CLOUD THICKNESS	-0.0004	0.11	-0.0003	0.04
PRECIPITABLE WATER	-0.012	0.76	0.017	0.59
TOTAL TOTALS	-0.010	0.72	0.010	0.55
RAINRATE mm/15 min	-0.109	0.70	0.037	0.93
mm/30 min	-0.147	0.48	-0.057	0.84
mm/hr	-0.195	0.22	-0.136	0.52
DURATION OF PCPN	-0.120	0.14	-0.144	0.12
AVERAGE RAINRATE mm/hr	-0.527	0.22	-0.46	0.55
AMOUNT OF PCPN	-0.105	0.16	-0.070	0.17
MAX 6 HR AMOUNT	-0.08	0.32	-0.017	0.85
% STNS WITH PCPN	0.707	0.68	-0.760	0.36

NO_3	WARM MONTHS		COLD MONTHS	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.0001	0.38	0.0002	0.38
SURFACE TEMPERATURE	-0.017	0.11	-0.006	0.51
SURFACE DEWPOINT	-0.016	0.13	-0.007	0.45
SURFACE WIND SPEED	-0.02	0.10	-0.026	0.04
850 MB TEMPERATURE	-0.015	0.19	-0.011	0.26
850 MB WIND SPEED	0.005	0.27	-0.011	0.03
CLOUD TOP	-0.0001	0.04	-0.00001	0.80
CLOUD THICKNESS	-0.0001	0.02	-0.00001	0.78
PRECIPITABLE WATER	-0.013	0.04	-0.018	0.05
TOTAL TOTALS	-0.006	0.21	-0.004	0.38
RAINRATE mm/15 min	-0.06	0.20	-0.015	0.84
mm/30 min	-0.05	0.13	-0.022	0.67
mm/hr	-0.051	0.05	-0.032	0.41
DURATION OF PCPN	-0.010	0.44	-0.021	0.21
AVERAGE RAINRATE mm/hr	-0.147	0.03	-0.167	0.22
AMOUNT OF PCPN	-0.023	0.05	-0.058	0.0004
MAX 6 HR AMOUNT	-0.009	0.47	-0.055	0.04
% STNS WITH PCPN	0.105	0.71	-0.81	0.001

Table 5.15: Results of the linear regressions between the continuous meteorological variables and the SO_4 and NO_3 readings.

Table 5.16 contains the results of the ANCOVA for the southeast region and Table 5.17 the results when the variables which were best for the southwest region were used.

Table 5.16: The ANCOVA for southeast region

WARM MONTHS

SO_4

	F	P>F	F	P>F	R	E^2
track of low	3.15	0.026	2.36	0.013	0.56	3.88
sfc 48 hr sector	3.08	0.012				
interaction	1.68	0.154				
duration of pcpn	0.22	0.640				
sfc wind speed	0.40	0.534				
850 wind direction	3.43	0.020	3.06	0.002	0.69	2.47
sfc 48 hr sector	3.72	0.005				
interaction	3.05	0.010				
duration of pcpn	0.11	0.741				
sfc wind speed	0.01	0.941				
850 48 hr sector	4.08	0.003	2.38	0.014	0.46	4.56
track of low	1.66	0.191				
interaction	0.43	0.787				
duration of pcpn	3.68	0.062				
sfc wind speed	0.80	0.377				
850 48 hr sector	4.54	0.001	2.56	0.010	0.47	4.10
850 wind direction	0.51	0.728				
interaction	2.12	0.133				
duration of pcpn	2.27	0.140				
sfc wind speed	0.00	0.973				

NO_3

	F	P>F	F	P>F	R	E^2
nature of pcpn	9.66	0.003	3.82	0.001	0.51	0.12
sfc 48 hr sector	2.20	0.054				
interaction	12.47	0.001				
amount of pcpn	3.23	0.080				
precipitable water	1.20	0.280				
airmass	2.40	0.047	1.64	0.100	0.60	0.09
sfc 48 hr sector	1.09	0.399				
interaction	1.61	0.156				
amount of pcpn	1.99	0.169				
precipitable water	0.30	0.586				
850 48 hr sector	3.95	0.004	2.24	0.017	0.61	0.09
airmass	1.73	0.136				
interaction	1.45	0.212				
amount of pcpn	3.07	0.089				
precipitable water	0.89	0.353				

cont'd

Table 5.16 cont'd

850 48 hr sector	4.47	0.001	5.02	0.0001	0.5	0.11
nature of pcpn	6.47	0.015				
interaction	5.36	0.025				
amount of pcpn	7.96	0.007				
precipitable water	3.62	0.064				
nature of pcpn	3.54	0.070	2.64	0.017	0.49	0.12
sfc 48 hr sector	1.59	0.177				
interaction	9.92	0.004				
amount of pcpn	3.61	0.067				
cloud thickness	0.83	0.370				
airmass	1.05	0.435	0.98	0.525	0.58	0.09
sfc 48 hr sector	0.88	0.545				
interaction	1.03	0.451				
amount of pcpn	1.55	0.230				
cloud thickness	0.33	0.574				
850 48 hr sector	2.42	0.60	1.82	0.085	0.63	0.08
airmass	1.37	0.266				
interaction	1.60	0.194				
amount of pcpn	3.33	0.082				
cloud thickness	1.21	0.283				
850 48 hr sector	2.66	0.032	3.34	0.004	0.50	0.11
nature of pcpn	2.71	0.109				
interaction	4.76	0.036				
amount of pcpn	7.46	0.010				
cloud thickness	2.46	0.126				

COLD MONTHS

SO_4

nature of pcpn	3.88	0.016	2.09	0.023	0.54	2.55
sfc 48 hr sector	1.10	0.380				
interaction	1.71	0.114				
sfc temperature	7.54	0.009				
nature of pcpn	5.46	0.003	3.32	0.0003	0.58	2.10
sfc 24 hr sector	2.77	0.017				
interaction	2.67	0.014				
sfc temperature	6.60	0.013				
sfc 24 hr sector	1.46	0.221	2.87	0.005	0.68	1.81
nature of pcpn	6.26	0.002				
interaction	2.95	0.013				
cloud thickness	4.14	0.051				
sfc temperature	0.48	0.496				

cont'd

Table 5.16 cont'd

sfc 48 hr sector	1.67	0.165	2.35	0.025	0.67	2.02
nature of pcpn	3.85	0.023				
interaction	2.35	0.052				
cloud thickness	3.12	0.091				
sfc temperature	1.85	0.187				
		NO_3				
850 24 hr sector	4.43	0.004	4.67	0.0001	0.56	0.19
nature of pcpn	5.13	0.004				
interaction	2.16	0.074				
precipitable water	3.41	0.071				
amount of pcpn	18.1	0.0001				

Table 5.17: The ANCOVA for southeast region with the variables which were best in the southwest region.

WARM MONTHS

		SO_4				
type of pcpn	0.87	0.358	1.29	0.265	0.32	5.58
sfc 24 hr sector	2.13	0.074				
interaction	0.27	0.893				
precipitable water	1.66	0.206				
duration of pcpn	0.37	0.547				
		NO_3				
synoptic type	3.04	0.022	3.89	0.0004	0.823	0.04
sfc 48 hr range	1.90	0.111				
interaction	5.50	0.0001				
duration of pcpn	0.14	0.712				
amount of pcpn	0.95	0.340				

COLD MONTHS

		SO_4				
cloud type	0.28	0.959	0.95	0.524	0.24	3.45
850 24 hr sector	0.86	0.495				
interaction	0.39	0.855				
cloud base height	4.99	0.030				
amount of pcpn	4.83	0.032				
		NO_3				
cloud type	0.82	0.577	1.51	0.123	0.33	0.25
850 24 hr sector	1.39	0.248				
interaction	0.67	0.653				
cloud base height	0.07	0.786				
amount of pcpn	12.50	0.001				

As in the other regions, the ANCOVA explained more of the variance in the SO_4 and NO_3 when the variables used were based on the ANOVA and regressions of the southeast region. The one exception was for the NO_3 for the warm months where the variables from the southwest region analysis (synoptic type, sfc 48 hr range, duration and amount of precipitation) performed better than those variables with the lower individual significance probabilities. This points up the non-objective nature of the process of choosing the best set of variables. Another possibility for the surprisingly good result with the variables from the southwest analysis in this case is that the ANCOVA only considers cases for which all the variables are available. In using only this subset, some of the cases which contributed to high significance probabilities for some of the variables may have been eliminated in the ANCOVA for this particular set of variables. Table 5.18 summarizes the results and Table 5.19 indicates the variables which were found to have the best performance in the ANCOVA for this region.

		R (from ANCOVA)	
		SE	SE(SW)
WARM MONTHS	SO_4	0.69	0.32
	NO_3	0.61	0.82
COLD MONTHS	SO_4	0.58	0.24
	NO_3	0.56	0.33

Table 5.18: The amount of variance of the dependent variable (SO_4 or NO_3) explained by the ANCOVA analysis (R).

SO_4		NO_3	
WARM MONTHS	COLD MONTHS	WARM MONTHS	COLD MONTHS
sfc 48 hr sector	sfc 24 hr sector	sfc 48 hr range	850 24 hr sector
850 mb wind dir	nature of pcpn	synoptic type	nature of pcpn
pcpn duration	sfc temperature	precipitable water	precipitable water
sfc wind speed		pcpn amount	pcpn amount

Table 5.19: The variables which performed best in the ANCOVA analysis for the southeast region.

5.4 Summary

Table 5.20 summarizes the amount of variance explained by the best analysis of covariance for the 4 regions.

		R (from ANCOVA)			
		SW	CE	SE	NW
WARM MONTHS	SO_4	0.47	0.44	0.69	0.83
	NO_3	0.56	0.80	0.82	0.81
COLD MONTHS	SO_4	0.64	0.79	0.58	0.61
	NO_3	0.64	0.70	0.56	0.65
AVERAGE		0.58	0.68	0.66	0.73

Table 5.20: Summary of the amount of variance explained by the best analysis of covariance for the 4 regions and the regional averages.

The amount of variance explained by the ANCOVA is in the reverse order to the averages of the SO_4 and NO_3 for the regions, i.e. the southwest region had the highest SO_4 and NO_3 readings and the ANCOVA was able to explain the least amount of variance for this region. The pattern follows for the southeast, central and northwest regions respectively. Overall, the amount of variance explained averaged 0.66.

An examination of the ANOVA and regressions of the 4 regions (Tables 4.4, 4.7, 5.2, 5.3, 5.8, 5.9, 5.14, and 5.15) can shed some light on those meteorological variables which were the most consistently highly associated with the SO_4 and NO_3 measurements. Referring to the beginning of section 4 the best variables are these (the first 3 are categorical variables and the last 2 continuous variables):

VARIABLE TYPE	BEST VARIABLE
synoptic situation	airmass
airmass history	sfc 48 hr sector
characterization of pcpn	type of pcpn in the warm months and the nature of the pcpn in the cold months.
airmass characteristics	surface temperature or precipitable water
rainfall	pcpn amount or duration.

6. Tests to Predict Annual Deposition from a Selected Sample of Days

The predictions of SO_4 and NO_3 values from the ANCOVA using the best set of variables for each region for both the warm and cold months served as the basis for categorizing the days. Eight classes were used such that the bounds of the classes divided the predictions of SO_4 and NO_3 into 8 groups with approximately the same number of observations. With this classification in place for both SO_4 and NO_3 for each day, region, and season, the following three experiments were run to see how well annual deposition statistics could be predicted from a selected sample of days.

a) Non-Weighted Average

For each category, the average deposition per day from the sample times the number of days of that particular category in the whole data set was calculated. These values for all the categories were then summed up to get the overall deposition. As a base line comparison, the average deposition per day from the selected number of days (regardless of the categorizations) times the number of days in the whole data set was also calculated. If the categorizations determined from the ANCOVA are useful in this application, the first calculation, referred to as prediction one, should perform better than the second (prediction two) at estimating annual deposition.

b) Weighted Average

This is similar to the above case a) except the sum of the deposition for the days in a given category in the sample is divided by the amount of rainfall received on those days and then multiplied by the total amount of precipitation received by that particular category within the whole data set. This reduces the variability introduced in the calculation of deposition from concentrations due to varying amounts of rainfall on the different days.

c) Weighted Average for the Individual Stations

Whereas the previous 2 methods dealt only with regional averages, here the depositions are calculated and compared with each of the 16 stations individually using the weighted average approach.

The criteria for selecting the days for the test were that they had to include examples of all the categorizations, of all months of the year, and be contained generally in groups of at least 3 or 4 consecutive days. Also, the days had to be the same for all regions. These restrictions were necessary to simulate the process which would be carried out if results of the Eulerian model were used to predict annual deposition. The days selected were the following:

	NO of DAYS
January 11-17	7
February 8-13	6
March 8-18	11
April 16-21	6
May 18-23	6
June 18-21,28,29	6
July 16-18,26-30	8
August 18-24	7
September 20-27	8
October 14-16	3
November 19-29	11
December 14-20	7

In all, 86 days were chosen.

Given in Table 6.1 for each region are the number of days of each of the 8 categories in the whole data set being considered and the number of days in the selected sample for each category.

Table 6.1: The number of days, by category, for the data set being considered (first number) and for the selected sample (second number) for each region.

NUMBER OF DAYS IN EACH
OF THE 8 CATEGORIES
(WHOLE DATA SET/SAMPLE)

SOUTHWEST REGION

	WARM MONTHS				COLD MONTHS			
CAT	SO_4		NO_3		SO_4		NO_3	
1	5	4	7	4	9	4	10	3
2	7	5	8	6	11	4	11	4
3	6	2	7	3	11	3	11	5
4	7	4	8	3	11	4	12	4
5	6	4	8	3	10	6	11	4
6	6	3	8	4	12	3	10	5
7	6	2	7	3	10	5	10	3
8	7	3	7	3	10	3	10	4

cont'd

Table 6.1 cont'd

CENTRAL REGION

CAT	WARM MONTHS SO_4		WARM MONTHS NO_3		COLD MONTHS SO_4		COLD MONTHS NO_3	
1	8	3	7	0	9	6	6	1
2	9	4	9	5	10	2	9	3
3	8	2	7	3	9	5	7	0
4	9	5	8	3	11	5	9	3
5	8	3	8	5	9	0	7	2
6	8	2	8	3	10	2	11	2
7	8	4	6	1	9	1	5	3
8	8	0	8	1	10	4	9	2

SOUTHEAST REGION

CAT	WARM MONTHS SO_4		WARM MONTHS NO_3		COLD MONTHS SO_4		COLD MONTHS NO_3	
1	6	2	7	0	9	3	5	1
2	7	3	9	5	8	1	8	2
3	7	3	5	1	6	4	10	5
4	7	4	9	5	11	4	9	2
5	5	2	6	5	9	2	6	4
6	8	4	8	2	10	1	9	2
7	6	1	6	1	7	1	8	4
8	7	4	8	4	9	2	8	1

NORTHWEST REGION

CAT	WARM MONTHS SO_4		WARM MONTHS NO_3		COLD MONTHS SO_4		COLD MONTHS NO_3	
1	6	2	7	4	5	1	6	0
2	7	2	10	2	6	1	6	2
3	8	5	8	2	6	2	7	2
4	6	1	9	1	6	2	6	2
5	8	1	9	2	6	0	6	2
6	8	0	10	2	6	2	7	0
7	6	2	8	1	6	2	6	2
8	8	2	9	2	6	0	7	2

Table 6.2 contains the results of the first test of estimating the annual deposition using non-weighted averages for the 4 regions. The unit for deposition in all the following tables is mg m^{-2}.

OBSERVED DEPOSITION	PREDICTION ONE	PREDICTION TWO	NO OF DAYS SAMPLE	SET	MONTHS	REGION
1699.535	2014.667	2034.546	27	50	SO_4 WARM	southwest
271.007	299.023	316.928	29	60	NO_3 WARM	
1074.615	1050.385	1059.523	32	84	SO_4 COLD	
241.371	282.649	274.855	32	85	NO_3 COLD	
1391.583	1271.018	1271.381	23	66	SO_4 WARM	central
154.670	183.356	160.352	21	61	NO_3 WARM	
702.781	793.232	692.399	25	77	SO_4 COLD	
183.760	188.870	180.715	16	63	NO_3 COLD	
1495.058	1770.407	1540.353	23	53	SO_4 WARM	southeast
212.401	235.813	247.264	23	58	NO_3 WARM	
1010.660	693.914	814.526	18	69	SO_4 COLD	
204.027	154.757	144.087	21	63	NO_3 COLD	
646.121	437.727	450.752	15	57	SO_4 WARM	northwest
105.368	108.877	90.567	16	70	NO_3 WARM	
245.217	153.094	165.797	10	47	SO_4 COLD	
53.575	53.081	51.348	12	51	NO_3 COLD	

Table 6.2: Deposition results using non-weighted averaging.

The following Table 6.3 gives the same results as Table 6.2 using the weighted calculations.

OBSERVED DEPOSITION	PREDICTION ONE	PREDICTION TWO	NO. OF DAYS SAMPLE	SET	MONTHS	REGION
1699.530	1808.050	1756.010	27	50	SO_4 WARM	southwest
271.016	292.813	285.101	29	60	NO_3 WARM	
1074.610	1109.290	993.714	32	84	SO_4 COLD	
241.373	255.227	260.318	32	85	NO_3 COLD	
1391.590	977.407	1104.570	23	66	SO_4 WARM	central
154.667	154.793	131.031	21	61	NO_3 WARM	
702.783	815.510	688.642	25	77	SO_4 COLD	
183.750	210.161	198.971	16	63	NO_3 COLD	
1495.060	1826.030	1681.020	23	53	SO_4 WARM	southeast
212.409	270.116	269.026	23	58	NO_3 WARM	
1010.660	957.081	1032.380	18	69	SO_4 COLD	
204.032	317.278	215.674	21	63	NO_3 COLD	
646.136	504.768	527.749	15	57	SO_4 WARM	northwest
105.357	108.000	102.626	16	70	NO_3 WARM	
245.207	237.790	244.141	10	47	SO_4 COLD	
53.576	67.999	72.145	12	51	NO_3 COLD	

Table 6.3: Deposition results using weighted averaging.

The following Table 6.4 contains the results of the weighted averaging for the 16 individual stations.

Table 6.4: Deposition results using weighted averaging for individual stations.

OBSERVED DEPOSITION	PREDICTION ONE	PREDICTION TWO	NUMBER SAMPLE	IN SET	MONTHS	STATION
1120.540	1275.235	1120.000	19	32	SO_4 WARM	1011
203.858	205.918	206.802	22	38	NO_3 WARM	
849.895	890.425	802.802	23	54	SO_4 COLD	
165.988	179.613	172.599	23	53	NO_3 COLD	
1561.920	1569.070	1615.230	21	42	SO_4 WARM	1021
225.512	224.273	220.497	22	47	NO_3 WARM	
854.680	747.379	778.719	23	64	SO_4 COLD	
185.855	185.654	210.850	23	62	NO_3 COLD	
972.620	1072.080	1030.620	19	31	SO_4 WARM	1031
151.306	178.553	162.656	20	38	NO_3 WARM	
829.165	859.081	703.964	16	36	SO_4 COLD	
160.039	168.656	152.701	16	36	NO_3 COLD	
1642.630	1765.010	1721.430	21	38	SO_4 WARM	2011
213.167	223.313	213.948	21	41	NO_3 WARM	
899.555	910.459	907.509	24	56	SO_4 COLD	
197.701	228.103	241.801	24	58	NO_3 COLD	
1237.210	1038.207	1049.660	19	53	SO_4 WARM	3011
114.572	132.278	113.210	17	47	NO_3 WARM	
573.895	542.270	599.593	21	66	SO_4 COLD	
155.003	203.160	190.944	14	55	NO_3 COLD	
1048.310	900.324	809.637	14	37	SO_4 WARM	3021
120.818	133.317	114.105	14	36	NO_3 WARM	
645.620	672.770	561.736	13	50	SO_4 COLD	
156.832	155.918	126'620	8	41	NO_3 COLD	
1131.220	891.301	861.826	19	44	SO_4 WARM	3031
110.286	109.929	96.522	17	39	NO_3 WARM	
437.295	523.663	526.940	14	42	SO_4 COLD	
104.343	150.997	136.616	10	34	NO_3 COLD	
1177.680	1037.542	976.166	20	49	SO_4 WARM	3041
122.757	129.974	111.289	17	41	NO_3 WARM	
540.810	543.769	574.829	14	46	SO_4 COLD	
141.332	203.423	173.889	10	39	NO_3 COLD	

cont'd

Table 6.4 cont'd

1412.450	1668.980	1522.970	20	42	SO_4 WARM	4011
171.038	226.004	207.359	19	43	NO_3 WARM	
836.845	809.845	909.082	17	57	SO_4 COLD	
160.186	249.280	173.856	20	52	NO_3 COLD	
1230.930	1247.744	1339.810	17	35	SO_4 WARM	4021
182.686	228.152	226.397	17	38	NO_3 WARM	
889.785	923.838	833.310	12	39	SO_4 COLD	
196.775	293.937	199.638	13	35	NO_3 COLD	
1032.180	1153.450	900.626	17	33	SO_4 WARM	4031
161.252	164.850	186.804	18	37	NO_3 WARM	
937.880	865.137	997.450	11	50	SO_4 COLD	
168.000	158.890	190.556	13	44	NO_3 COLD	
624.835	833.982	682.128	15	32	SO_4 WARM	4041
85.701	93.476	100.685	16	33	NO_3 WARM	
344.935	190.102	182.951	5	33	SO_4 COLD	
49.658	5.684	5.928	5	29	NO_3 COLD	
310.445	174.372	163.492	5	25	SO_4 WARM	6051
44.878	48.744	40.200	5	32	NO_3 WARM	
178.035	230.351	253.167	6	24	SO_4 COLD	
36.140	62.445	68.406	7	29	NO_3 COLD	
214.005	40.229	39.525	2	12	SO_4 WARM	6061
30.850	8.091	6.052	3	16	NO_3 WARM	
18.590	16.363	16.363	3	6	SO_4 COLD	
6.811	5.561	5.561	5	8	NO_3 COLD	
403.975	349.248	380.424	11	39	SO_4 WARM	6071
71.662	69.266	71.314	11	42	NO_3 WARM	
122.090	84.096	85.696	7	28	SO_4 COLD	
35.195	35.462	27.485	10	35	NO_3 COLD	
472.250	584.340	638.911	12	40	SO_4 WARM	6081
84.293	95.144	87.071	12	46	NO_3 WARM	
184.485	226.876	228.618	3	25	SO_4 COLD	
40.083	57.591	55.426	6	30	NO_3 COLD	

From Tables 6.2 to 6.4 the absolute fractional error (defined as the absolute value of the difference between the observed and predicted annual deposition divided by the observed annual deposition) was calculated for the 2 types of predictions (with and without the categorizations being used) from the 3 tests performed. The results are displayed in Tables 6.5 to 6.13. Shown in the final two columns are the number of times one prediction was better than the other, i.e. a smaller absolute fractional error. Table 6.5 gives the results for all the data, Tables 6.6 to 6.9 divide the data by regions, Tables 6.10 and 6.11 stratify the data by warm and cold months and Tables 6.12 and 6.13 divide the data depending on the number of observations in the selected sample.

	ABSOLUTE FRACTIONAL ERROR					
	SO_4		NO_3			
	PREDICTION ONE	PREDICTION TWO	PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	BEST PREDICTION TWO
NON WEIGHTED	0.20	0.15	0.11	0.13	6	10
WEIGHTED	0.13	0.08	0.18	0.18	5	11
STATIONS	0.17	0.17	0.22	0.20	35	29

Table 6.5: Deposition errors for all the data

	ABSOLUTE FRACTIONAL ERROR					
	SO_4		NO_3			
	PREDICTION ONE	PREDICTION TWO	PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	BEST PREDICTION TWO
NON WEIGHTED	0.10	0.11	0.14	0.15	2	2
WEIGHTED	0.05	0.05	0.07	0.07	2	2
STATIONS	0.07	0.06	0.07	0.07	7	9

Table 6.6: Deposition errors for the southwest region.

	ABSOLUTE FRACTIONAL ERROR					
	SO_4		NO_3			
	PREDICTION ONE	PREDICTION TWO	PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	BEST PREDICTION TWO
NON WEIGHTED	0.11	0.05	0.11	0.03	0	4
WEIGHTED	0.23	0.11	0.07	0.12	1	3
STATIONS	0.12	0.15	0.19	0.16	9	7

Table 6.7: Deposition errors for the central region.

	ABSOLUTE FRACTIONAL ERROR					
	SO_4		NO_3			
	PREDICTION ONE	PREDICTION TWO	PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	BEST PREDICTION TWO
NON WEIGHTED	0.25	0.11	0.18	0.23	2	2
WEIGHTED	0.14	0.07	0.41	0.16	0	4
STATIONS	0.16	0.13	0.33	0.24	8	8

Table 6.8: Deposition errors for the southeast region.

	ABSOLUTE FRACTIONAL ERROR SO_4 PREDICTION ONE	PREDICTION TWO	NO_3 PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	TWO
NON WEIGHTED	0.35	0.31	0.02	0.09	2	2
WEIGHTED	0.12	0.09	0.15	0.10	2	2
STATIONS	0.32	0.35	0.29	0.33	11	5

Table 6.9: Deposition errors for the northwest region.

	ABSOLUTE FRACTIONAL ERROR SO_4 PREDICTION ONE	PREDICTION TWO	NO_3 PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	TWO
NON WEIGHTED	0.19	0.15	0.11	0.13	4	4
WEIGHTED	0.20	0.14	0.09	0.21	2	6
STATIONS	0.20	0.19	0.14	0.13	17	15

Table 6.10: Deposition errors for the warm months.

	ABSOLUTE FRACTIONAL ERROR SO_4 PREDICTION ONE	PREDICTION TWO	NO_3 PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	TWO
NON WEIGHTED	0.21	0.14	0.11	0.12	2	6
WEIGHTED	0.07	0.03	0.26	0.14	3	5
STATIONS	0.13	0.16	0.30	0.26	18	14

Table 6.11: Deposition errors for the cold months.

	ABSOLUTE FRACTIONAL ERROR SO_4 PREDICTION ONE	PREDICTION TWO	NO_3 PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	TWO
NON WEIGHTED	0.25	0.18	0.10	0.11	3	7
WEIGHTED	0.15	0.09	0.20	0.14	3	7
STATIONS	0.22	0.25	0.36	0.30	16	14

Table 6.12: Deposition errors when the ratio of sampled to total observations were less than 0.35.

	ABSOLUTE FRACTIONAL ERROR					
	SO_4		NO_3			
	PREDICTION ONE	PREDICTION TWO	PREDICTION ONE	PREDICTION TWO	BEST PREDICTION ONE	BEST PREDICTION TWO
NON WEIGHTED	0.13	0.08	0.13	0.16	3	3
WEIGHTED	0.11	0.08	0.14	0.13	2	4
STATIONS	0.11	0.10	0.10	0.11	19	15

Table 6.13: Deposition errors when the ratio of sampled to total observations were less than 0.35.

From the previous 9 tables the following generalizations can be made:

i) The weighted averaging performed better for the SO_4 depositions but not for the NO_3 depositions (Table 6.5).

ii) Predictions using the categorizations performed marginally better for the individual stations (35 to 29) while predictions not using the categorizations were better for the regional averages, both weighted and non-weighted (Table 6.5).

iii) For the individual stations, the southwest region was the best while the northwest region was the poorest in estimating annual deposition (Tables 6.6 to 6.9).

iv) By season, SO_4 estimates were better in the cold months while the NO_3 estimates were better in the warm months (Tables 6.10 and 6.11).

v) The estimates improved with the number of cases in the sample. When the selected sample had less than one-third of the total observations, the errors were around 20% while they were around 10% when more than one-third of the days were in the sample (Tables 6.12 to 6.13).

Overall however, there is no compelling evidence that the categorizations based upon the ANCOVA for each region are useful in estimating annual deposition. The variabilities within the categories are too large.

7. Summary and Conclusions

Meteorological data were analysed on those days in 1982 when SO_4 or NO_3 measurements were recorded by the any of the 16 APIOS stations. The province was divided into 4 regions (southwest, central, southeast and northwest) to reflect the grouping of the APIOS stations. Data used in the meteorological analysis included surface weather maps from the Ontario Weather Centre (every 6 hours)), U.S. Weather Bureau surface and 500 mb maps (daily), CMC 850 mb maps (every 12 hours), representative surface hourly reports and upper air soundings for the particular precipitation event, and climatological precipitation data, both daily and hourly when available. Fields extracted were the synoptic situation, the track of the controlling low, the airmasses involved, 24 and 48 hr surface and 850 mb trajectory information (sector and range), various surface and upper air temperatures and winds, and intensity amount and duration variables of the area-wide precipitation.

The relationships between the SO_4 and NO_3 readings for the southwest region were examined. For the discrete variables (Table 4.3c), the trajectories associated with high SO_4 and NO_3 measurements were similar but for the other meteorological fields, the important factors were dissimilar. Synoptic conditions had some effect on the high SO_4 readings but not on the high NO_3 readings. The airmasses associated with them were also different, mP and mT air with SO_4, and cA cmA and mA with NO_3. High SO_4 readings were associated with convective situations and rainfall, while high NO_3 readings were associated with snow but had no relationship to the type of precipitation (convective or continuous).

For the continuous variables, the general trend (Table 4.8) is that high SO_4 readings were associated with high temperatures and moisture and low precipitation events, low cloud bases, and low windspeeds. For NO_3, high readings were associated with low temperatures and moisture, low wind speeds, low cloud bases, and low precipitation events.

The data were subdivided into 6 warm months (April to September) and 6 cold months to reduce the variability of the SO_4 and NO_3 readings while still maintaining enough data in each set to perform statistical tests. An analysis of variance was performed between the SO_4 and NO_3 measurements and the discrete meteorological variables while linear regressions were done between the SO_4 and NO_3 readings and the continuous meteorological variables to search for significant variables. Those variables which showed promise individually were then combined using the analysis of covariance technique to try to explain as much of the variance in the SO_4 and NO_3 readings as possible.

Tests indicated that better results were obtained by examining each region separately in determining the best set of variables. Different meteorological conditions among regions and the different observing networks in each region (both meteorological and APIOS stations) with regard to the type and density, and spatial distribution of stations were the underlying causes. From the ANCOVA the following were the variables which were deemed the best set in each region.

SOUTHWEST REGION

SO_4 WARM MONTHS	SO_4 COLD MONTHS	NO_3 WARM MONTHS	NO_3 COLD MONTHS
precipitation type	cloud type	synoptic type	cloud type
sfc 24 hr sector	850 24 hr sector	sfc 48 hr range	850 24 hr sector
precipitable water	cloud base height	duration of pcpn	cloud base height
duration of pcpn	amount of pcpn	amount of pcpn	amount of pcpn

CENTRAL REGION

SO_4 WARM MONTHS	SO_4 COLD MONTHS	NO_3 WARM MONTHS	NO_3 COLD MONTHS
precipitation type	airmass	sfc 48 hr sector	sfc 48 hr sector
sfc 48 hr sector	sfc 48 hr sector	850 wind direction	nature of pcpn
pcpn duration	sfc temperature	pcpn duration	cloud base height
sfc temperature		sfc wind speed	pcpn amount

SOUTHEAST REGION

SO_4 WARM MONTHS	SO_4 COLD MONTHS	NO_3 WARM MONTHS	NO_3 COLD MONTHS
sfc 48 hr sector	sfc 24 hr sector	sfc 48 hr range	850 24 hr sector
850 mb wind dir	nature of pcpn	synoptic type	nature of pcpn
pcpn duration	sfc temperature	precipitable water	precipitable water
sfc wind speed		pcpn amount	pcpn amount

NORTHWEST REGION

SO_4 WARM MONTHS	SO_4 COLD MONTHS	NO_3 WARM MONTHS	NO_3 COLD MONTHS
airmass	sfc 24 hr range	airmass	airmass
sfc 48 hr range	synoptic type	sfc 48 hr sector	850 48 hr sector
cloud base height	sfc temperature	sfc temperature	amount of pcpn
sfc temperature	precipitable water	stations with pcpn	

In general, the ANCOVA with these variables was able to explain about two-thirds of the variance in the SO_4 and NO_3 measurements.

From the ANOVA and the linear regressions performed on the 4 regions, the following meteorological variables were the most consistently strongly associated with the SO_4 and NO_3 variations for the respective type of variable.

synoptic situation	airmass
airmass history	sfc 48 hr sector
characterization of pcpn	type of pcpn in the warm months and the nature of the pcpn in the cold months.
airmass characteristics	surface temperature or precipitable water
rainfall	pcpn amount or duration.

For more conclusive results in future experiments or studies in statistical modelling of deposition amounts, these are the meteorological factors which should be considered and designed into the data collection efforts.

The predictions of SO_4 and NO_3 based on the ANCOVA were then used to classify the days in an effort to estimate annual deposition from a selected sample of days. These results showed that annual deposition could be estimated to within 10% to 20% when approximately one-third of the days were sampled'. But the categorizations used were not significantly better than treating all the days the same in this regard i.e. stratifying the days sampled by categories showed no significant improvement. The variation in daily deposition within the categories is too large.

To improve upon this situation a number of problems associated with the data must be rectified. The most important are:

1. The precipitation events need to be better and more uniformly defined in their timing. Drastically different times for the beginning and end of precipitation events at neighbouring APIOS stations were noted.

2. The meteorological observations should be taken at the same locale as the APIOS sites. Differences in distances from the APIOS sites to the closest AES hourly station among the 4 regions (and the different hours of operations of such stations) added noise to the data set.

3. Better time resolution on the meteorological and precipitation chemistry observations are necessary. During significant rainfalls, the synoptic situation is often rapidly changing so that any depiction over 24 hrs can be misleading.

4. More detailed meteorological cloud observations (e.g. types and bases) would be useful. The analysis in the southwest region showed these to be important but the other regions, where these observations may not have been as good or as representative, did not support this. If several years of precipitation chemistry measurements are available, it may be worthwhile to compare the precipitation chemistry (perhaps concentration contours by month or season) to the similar cloud and precipitation climatology stratified by frequency, nature, type, and/or amount.

Appendix A. REGIONS FOR MOE APIOS CLIMATOLOGY

Surface Stations

Southwestern Region

1. APIOS Stations

   - Melbourne
   - Longwoods
   - North Easthope
   - Wellesley

2. Hourly and Synoptic Stations

   - Windsor (YQG)
   - Sarnia (YZR)
   - London (YXU)
   - Simcoe (WMK)
   - Hamilton (YHM)
   - Toronto International Airport (YYZ)
   - Toronto Island (YTZ)
   - Mount Forest (WMN)
   - Kitchener (YKF)
   - St. Catherines (YSN)
   - Goderich (WGD)

3. Climatological Stations: districts 613,614, 612 south of 44.5°N, and 615 west of 80°W or south of 44°N.

Central Region

1. APIOS Stations

   - Raven Lake
   - Balsam Lake
   - Nithgrove
   - Dorset

2. Hourly and Synoptic Stations

   - Wiarton (YVV)
   - Muskoka (YQA)
   - Gore Bay (YZE)
   - Sudbury (YSB)
   - North Bay (YYB)
   - Peterborough (YPQ)

3. Climatological Stations: districts 609, 611, 616, 612 north of 44.5°N, 606 south of 46.75°N, 608 south of 46.75°N, and 615 between 78°W and 79°W and north of 44°N between 79°W and 80°W.

Southeastern Region

1. APIOS Stations

   - Whitman Creek
   - Railton
   - Charleston Lake

- Graham Lake

2. Hourly and Synoptic Stations

   - Trenton (YTR)
   - Kingston (YGK)
   - Ottawa International Airport (YOW)
   - Petawawa (YWA)

3. Climatological Stations: districts 610, and 615 east of 78°W.

Northwestern Region

1. APIOS Stations

   - Forbes Township
   - Quetico Centre
   - Lac La Croix
   - Fernberg

2. Hourly and Synoptic Stations

   - Thunder Bay (YQT)
   - Armstrong (YYW)
   - Sioux Lookout (YXL)
   - Dryden (YHD)
   - Atikokan (WIB)
   - International Falls, U.S. (INL)
   - Hibbing, U.S. (HIB)

3. Climatological Stations: district 604 between 88°W and 93°W and south of 50.5°N.

Upper Air Stations

North Region

1. International Falls (INL)
2. Trout Lake (WTL)

South Region

1. Flint (FNT)
2. Buffalo (BUF)
3. Maniwaki (YMW)
4. Sault Ste Marie (SSM)

Appendix B: SUMMARY OF THE DATA TO BE COLLECTED

1. Synoptic type

    - warm front
    - cold front
    - stationary front
    - occluded low
    - cold low
    - airmass

2. Track of controlling low

    - Alberta low
    - Colorado low
    - Texas low coming north of the Appalachians
    - Texas low going south of the Appalachians
    - Low forming in the Great Lakes region

3. Airmass(es) involved

    - maritime Tropical air
    - maritime polar air
    - maritime arctic air
    - cold maritime arctic air
    - continental arctic air

4. Sector (octants) of air 24 and 48 hours previous at surface and 850 mb.

5. Distance of the origin of the 24 and 48 hour trajectories from the main APIOS observing site.

6. 850 mb. temperature

7. 850 mb. wind

8. Precipitable water

9. Stability index

10. Cloud base height

11. Cloud top

12. Cloud thickness

13. Surface temperature

14. Surface dewpoint

15. Surface wind

16. Predominant type of cloud

17. Nature of precipitation

    - rain
    - snow
    - ice
    - freezing precipitation

18. Type of precipitation

    - intermittant
    - continuous
    - showery

19. Average rainfall rate (mm/hr)

20. Maximum rainfall rate (mm/hr, mm/30 min, mm/15 min)

21. Average duration of precipitation event

22. Average precipitation amount

23. Percentage of stations receiving precipitation

24. Average snowfall amount

25. Average snowfall rate (cm/6 hr)

Appendix C

The following is a summary of the data available for the 4 regions (Southwest (SW), Central (CE), Southeast (SE), and Northwest (NW)). Sulfate, nitrate, and APIOS rainfall data are averages from the APIOS stations which reported precipitation on a particular day. For the discrete variables the first number is the number of observations of a given category followed by its percentage of the available observations in brackets. For the continuous variables, the mean and standard deviation (SD) is given. Missing data (indicated by MSG) refers to either the fact that data were not available, a reliable determination of the variable could not be made with the data available (e.g. predominant cloud type), or there were no data (e.g. no rainfall reports).

Table C1: A summary of the meteorological data collected.

	SW	CE	SE	NW
TOTAL NO OF OBS	183	189	151	161
SYNOPTIC TYPE				
WARM FRONT	40 (22)	38 (20)	30 (20)	28 (17)
COLD FRONT	47 (26)	42 (22)	32 (21)	18 (11)
STATIONARY FRONT	16 (9)	10 (5)	8 (5)	15 (9)
OCCLUDED LOW	40 (22)	47 (25)	40 (26)	61 (38)
COLD LOW	8 (4)	13 (7)	10 (7)	12 (7)
AIRMASS	21 (11)	20 (11)	15 (10)	13 (8)
WARM AND COLD FRONT	11 (6)	19 (10)	16 (11)	14 (9)
TRACK OF LOW				
ALBERTA LOW	55 (30)	61 (32)	45 (30)	106 (66)
COLORADO LOW	85 (46)	88 (47)	70 (46)	51 (32)
TEXAS LOW NORTH	13 (7)	7 (4)	10 (7)	2 (1)
TEXAS LOW SOUTH	11 (6)	8 (4)	11 (7)	0
GREAT LAKES	19 (10)	22 (12)	14 (9)	1 (1)
HUDSON BAY LOW	0	3 (2)	1 (1)	1 (1)

	SW	CE	SE	NW
AIRMASS				
CA	33 (18)	25 (13)	19 (13)	29 (18)
CMA	3 (2)	3 (2)	2 (1)	5 (3)
MA	13 (7)	27 (14)	23 (15)	26 (16)
MP	4 (2)	5 (3)	4 (3)	2 (1)
MT	2 (1)	1 (1)	1 (1)	0
CA CMA	6 (3)	12 (6)	7 (5)	11 (7)
CA MA	35 (19)	32 (17)	30 (20)	26 (16)
CMA MA	17 (9)	15 (8)	14 (9)	10 (6)
MA MP	50 (27)	56 (30)	40 (26)	40 (25)
MP MT	20 (11)	12 (6)	11 (7)	12 (7)
MSG	0	1	0	0
850 MB TRAJECTORY				
24 HR SECTOR				
NNW	16 (9)	12 (7)	8 (5)	25 (16)
WNW	47 (26)	39 (21)	25 (17)	35 (23)
WSW	72 (40)	85 (46)	67 (45)	39 (25)
SSW	37 (21)	38 (21)	43 (29)	33 (22)
SSE	0	5 (3)	3 (2)	9 (6)
ESE	4 (2)	4 (2)	4 (3)	1 (1)
ENE	2 (1)	1 (1)	0	2 (1)
NNE	1 (1)	0	0	9 (6)
MSG	4	5	1	8
24 HR RANGE (KM)				
<200	5 (3)	9 (5)	6 (4)	20 (13)
200-400	42 (23)	28 (15)	17 (11)	37 (24)
400-600	30 (17)	36 (20)	31 (21)	45 (29)
600-800	35 (19)	47 (26)	35 (23)	36 (24)
800-1000	28 (16)	25 (14)	28 (19)	8 (5)
1000-1200	16 (9)	17 (9)	13 (9)	3 (2)
1200-1400	17 (9)	17 (9)	14 (9)	3 (2)
1400-1600	5 (3)	1 (1)	3 (2)	0
1600-1800	2 (1)	3 (2)+	1 (1)	1 (1)
1800-2000	0	1 (1)	2 (1)	0
MSG	3	5	1	8

	SW	CE	SE	NW
48 HR SECTOR				
NNW	16 (10)	18 (10)	6 (4)	21 (15)
WNW	51 (31)	48 (27)	30 (21)	41 (30)
WSW	63 (38)	69 (39)	67 (48)	32 (23)
SSW	28 (17)	34 (19)	28 (20)	31 (22)
SSE	4 (2)	4 (2)	2 (1)	7 (5)
ESE	0	2 (1)	4 (3)	2 (1)
ENE	1 (1)	0	2 (1)	0
NNE	1 (1)	0	1 (1)	4 (3)
MSG	19	14	11	23
48 HR RANGE (KM)				
<200	3 (2)	2 (1)	1 (1)	2 (1)
200-400	7 (4)	6 (3)	4 (3)	11 (8)
400-600	11 (6)	13 (7)	7 (5)	22 (16)
600-800	21 (12)	16 (9)	12 (8)	32 (23)
800-1000	21 (12)	21 (12)	21 (14)	21 (15)
1000-1200	23 (13)	24 (13)	18 (12)	22 (16)
1200-1400	30 (17)	23 (13)	26 (18)	13 (9)
1400-1600	28 (16)	21 (12)	14 (10)	6 (4)
1600-1800	19 (11)	26 (15)	19 (13)	7 (5)
1800-2000	12 (7)	19 (11)	10 (7)	2 (1)
2000-2200	4 (2)	7 (4)	10 (7)	0
2200-2400	0	1 (1)	3 (2)	0
MSG	4	10	6	23
SURFACE TRAJECTORY				
24 HR SECTOR				
NNW	12 (7)	14 (8)	10 (7)	18 (12)
WNW	21 (13)	15 (9)	10 (7)	9 (6)
WSW	30 (19)	37 (21)	26 (18)	8 (5)
SSW	44 (27)	37 (21)	46 (33)	33 (22)
SSE	14 (9)	32 (18)	17 (12)	36 (24)
ESE	15 (9)	20 (12)	23 (16)	18 (12)
ENE	11 (7)	9 (5)	5 (4)	13 (9)
NNE	14 (9)	10 (6)	4 (3)	12 (8)
MSG	22	15	10	14

	SW	CE	SE	NW
24 HR RANGE (KM)				
<200	28 (17)	27 (15)	19 (13)	22 (15)
200-400	43 (27)	36 (21)	31 (22)	48 (32)
400-600	40 (25)	48 (27)	46 (32)	38 (26)
600-800	24 (15)	34 (19)	23 (16)	26 (17)
800-1000	16 (10)	19 (11)	8 (6)	6 (4)
1000-1200	8 (5)	7 (4)	14 (10)	8 (5)
1200-1400	3 (2)	4 (2)	2 (1)	1 (1)
MSG	21	14	8	12
SURFACE TRAJECTORY				
48 HR SECTOR				
NNW	20 (15)	16 (10)	12 (9)	16 (12)
WNW	16 (12)	28 (17)	28 (21)	8 (6)
WSW	28 (20)	28 (17)	22 (17)	7 (5)
SSW	26 (19)	34 (21)	28 (21)	27 (21)
SSE	12 (9)	17 (10)	15 (11)	28 (22)
ESE	10 (7)	17 (10)	13 (10)	15 (12)
ENE	14 (10)	9 (6)	5 (4)	16 (12)
NNE	12 (9)	14 (9)	8 (6)	12 (9)
MSG	45	26	20	32
48 HR RANGE (KM)				
<200	9 (6)	9 (5)	6 (4)	14 (11)
200-400	25 (18)	23 (14)	12 (9)	32 (24)
400-600	27 (19)	35 (21)	36 (27)	27 (21)
600-800	31 (22)	28 (17)	18 (13)	25 (19)
800-1000	24 (17)	20 (12)	28 (21)	11 (8)
1000-1200	7 (5)	30 (18)	17 (13)	16 (12)
1200-1400	5 (3)	13 (8)	13 (10)	3 (2)
1400-1600	5 (3)	6 (4)	3 (2)	3 (2)
1600-1800	3 (2)	2 (1)	2 (1)	0
1800-2000	2 (1)	0	0	0
2000-2200	1 (1)	0	0	0
MSG	44	23	16	30
TYPE OF PRECIPITATION				
CONTINUOUS	88 (54)	68 (41)	73 (52)	71 (51)
CONVECTIVE	74 (46)	99 (59)	68 (48)	68 (49)
MSG	21	22	10	22

	SW	CE	SE	NW
NATURE OF PRECIPITATION				
RAIN	99 (61)	103 (62)	95 (67)	95 (68)
SNOW	54 (33)	58 (35)	35 (25)	36 (26)
FREEZING	2 (1)	2 (1)	3 (2)	0
MIXED	7 (4)	4 (2)	8 (6)	8 (6)
MSG	21	22	10	22
PREDOMINANT CLOUDS				
TOWERING CUMULUS	3 (2)	11 (7)	5 (4)	11 (9)
ALTOCUMULUS	2 (1)	2 (1)	2 (1)	2 (2)
ALTOSTRATUS	4 (3)	3 (2)	1 (1)	2 (2)
CUMULONIMBUS	21 (13)	11 (7)	18 (13)	21 (17)
CUMULUS	14 (9)	22 (14)	8 (6)	12 (9)
NIMBOSTRATUS	29 (18)	12 (8)	12 (9)	0
STRATOCUMULUS	70 (45)	82 (51)	77 (56)	60 (47)
STRATUS	14 (9)	17 (11)	15 (11)	19 (15)
MSG	26	29	13	34
SURFACE WIND SECTOR				
NNW	16 (10)	8 (4)	12 (8)	16 (11)
WNW	31 (18)	32 (18)	11 (7)	18 (12)
WSW	28 (17)	28 (16)	23 (15)	16 (11)
SSW	25 (15)	25 (14)	28 (19)	13 (9)
SSE	26 (15)	34 (19)	20 (13)	9 (6)
ESE	16 (9)	22 (12)	15 (10)	21 (14)
ENE	14 (8)	10 (6)	25 (17)	47 (31)
NNE	11 (7)	13 (7)	16 (11)	10 (7)
CALM	2 (1)	6 (3)	0	1
MSG	14	11	1	10
850 MB WIND SECTOR				
NNW	15 (9)	22 (14)	3 (2)	18 (14)
WNW	40 (25)	40 (25)	26 (19)	28 (22)
WSW	60 (38)	63 (40)	75 (55)	24 (18)
SSW	24 (15)	21 (13)	27 (20)	28 (22)
SSE	8 (5)	5 (3)	3 (2)	16 (12)
ESE	4 (3)	3 (2)	0	6 (5)
ENE	5 (3)	4 (2)	2 (1)	3 (2)
NNE	2 (1)	0	0	8 (5)
MSG	25	31	15	30

	SW	CE	SE	NW
CLOUD BASE HEIGHT (M)				
MEAN	666	658	718	749
SD	500	498	431	516
MSG	26	29	14	39
SURFACE TEMPERATURE (°C)				
MEAN	5.5	6.5	6.9	5.8
SD	10.7	10.0	9.4	11.0
MSG	15	10	1	10
SURFACE DEWPOINT (°C)				
MEAN	3.4	3.9	5.1	3.3
SD	10.7	10.3	9.3	11.2
MSG	15	10	1	10
SURFACE WIND SPEED (m/s)				
MEAN	9.2	8.4	8.7	6.5
SD	5.7	4.7	5.3	4.2
MSG	14	11	1	10
850 MB TEMPERATURE (°C)				
MEAN	2.7	2.4	3.9	3.6
SD	10.4	10.2	8.6	10.5
MSG	15	23	13	28
850 MB WIND SPEED (kts)				
MEAN	26	24	28	21
SD	13	12	15	11
MSG	24	31	15	31
CLOUD TOP (m)				
MEAN	3553	3520	3666	3603
SD	1982	2015	2052	1847
MSG	43	54	35	55
CLOUD THICKNESS (m)				
MEAN	2912	2883	3170	2842
SD	1993	2055	2049	1791
MSG	61	71	46	75

	SW	CE	SE	NW
PRECIPITABLE WATER (mm)				
MEAN	19.5	18.8	20.6	18.7
SD	12.0	11.0	10.8	9.8
MSG	17	26	15	28
TOTALS TOTALS				
MEAN	12.9	12.7	16.4	16.3
SD	17.6	16.6	15.7	15.2
MSG	15	24	13	28
MAXIMUM RAINRATE (mm/15 min)				
MEAN	2.0	1.6	1.9	1.9
SD	1.7	1.2	1.3	2.4
MSG	74	77	57	67
MAXIMUM RAINRATE (mm/30 min)				
MEAN	2.7	2.2	2.6	2.5
SD	2.2	1.7	1.8	3.0
MSG	74	77	57	67
MAXIMUM RAINRATE (mm/hr)				
MEAN	3.5	2.9	3.5	3.3
SD	2.7	2.1	2.3	3.9
MSG	74	76	57	67
DURATION OF PRECIPITATION (hr)				
MEAN	7.5			
7.8	7.7	9.6		
SD	5.0	5.4	5.2	6.1
MSG	77	77	67	75
PRECIPITATION RATE (mm/hr)				
MEAN	1.1	0.9	1.2	0.9
SD	0.9	0.7	0.8	1.2
MSG	77	77	67	76

	SW	CE	SE	NW
DAILY AMOUNT (mm)				
MEAN	6.3	5.8	6.1	6.3
SD	5.2	4.3	4.6	5.8
MSG	2	1	0	8
MAXIMUM 6 HR AMOUNT (mm)				
MEAN	4.3	4.5	4.6	4.5
SD	3.8	4.0	4.0	5.0
MSG	17	17	13	29
% OF STNS WITH PRECIP				
MEAN	0.66	0.72	0.72	0.59
SD	0.27	0.23	0.26	0.31
SO4 (mg/l)				
MEAN	3.75	2.99	3.55	1.32
SD	2.82	3.08	2.59	1.32
MSG	7	2	6	4
NO3 (mg/l)				
MEAN	0.76	0.61	0.75	0.26
SD	0.63	0.52	0.58	0.22
MSG	7	3	6	3
APIOS PRECIPITATION (mm)				
MEAN	7.0	6.0	7.5	7.1
SD	6.9	5.7	6.9	6.2
MSG	3	0	9	9

Appendix D

Table D1: Sulfate and Nitrate data as a function of the categories of the discrete variables.

	SO4		NO3	
	MEAN	SD	MEAN	SD
SYNOPTIC TYPE				
WARM FRONT	4.20	2.73	0.87	0.66
COLD FRONT	3.66	2.49	0.67	0.62
STATIONARY FRONT	4.96	3.49	0.87	0.82
OCCLUDED LOW	3.24	3.47	0.76	0.53
COLD LOW	2.51	1.49	0.72	0.57
AIRMASS	3.27	2.84	0.66	0.60
WARM AND COLD FRONT	4.46	2.81	0.89	0.69
TRACK OF LOW				
ALBERTA LOW	3.56	2.67	0.82	0.63
COLORADO LOW	4.23	2.66	0.74	0.65
TEXAS LOW NORTH	2.55	1.74	0.59	0.43
TEXAS LOW SOUTH	3.69	4.97	0.71	0.46
GREAT LAKES	2.96	2.81	0.84	0.73
AIRMASS				
CA	2.30	2.21	0.76	0.56
CMA	2.07	1.66	0.52	0.21
MA	2.50	1.48	0.45	0.29
MP	4.71	2.21	0.61	0.35
MT	3.29	0.05	0.45	0.12
CA CMA	2.57	1.76	0.71	0.63
CA MA	3.69	3.03	0.95	0.79
CMA MA	4.55	2.31	1.10	0.71
MA MP	4.27	2.72	0.67	0.60
MP MT	5.56	3.72	0.72	0.53

	SO4		NO3	
	MEAN	SD	MEAN	SD
850 MB TRAJECTORY				
24 HR SECTOR				
NNW	2.02	1.94	0.44	0.48
WNW	4.14	2.95	0.95	0.71
WSW	4.13	2.80	0.84	0.57
SSW	3.70	3.00	0.61	0.66
ESE	2.04	1.34	0.33	0.22
ENE	3.26	0.11	0.72	0.36
NNE	1.22	--	0.60	--
24 HR RANGE (KM)				
<200	4.02	3.69	1.14	0.87
200-400	5.11	3.47	0.90	0.70
400-600	3.17	2.00	0.72	0.56
600-800	4.09	3.15	0.84	0.73
800-1000	3.04	2.36	0.76	0.60
1000-1200	2.63	1.97	0.63	0.55
1200-1400	3.01	1.36	0.54	0.38
1400-1600	3.88	3.42	0.44	0.20
1600-1800	3.37	2.12	0.41	0.30
48 HR SECTOR				
NNW	3.47	4.22	0.49	0.43
WNW	3.62	2.84	0.88	0.67
WSW	4.51	2.72	0.94	0.71
SSW	3.68	2.56	0.68	0.44
SSE	2.04	1.34	0.33	0.22
ENE	3.19	--	0.47	--
NNE	0.85	--	0.17	--
48 HR RANGE (KM)				
<200	8.01	8.22	0.91	0.42
200-400	4.74	3.17	0.93	0.79
400-600	4.63	4.28	0.90	1.02
600-800	4.75	2.53	0.97	0.63
800-1000	3.82	2.48	0.70	0.34
1000-1200	3.95	2.61	0.77	0.53
1200-1400	2.73	1.98	0.55	0.47
1400-1600	3.44	2.77	0.75	0.75
1600-1800	3.54	2.41	0.83	0.72
1800-2000	3.41	2.44	0.81	0.67
2000-2200	2.59	1.55	0.78	0.43

	SO4 MEAN	SO4 SD	NO3 MEAN	NO3 SD
SURFACE TRAJECTORY				
24 HR SECTOR				
NNW	2.98	3.21	0.57	0.42
WNW	3.75	2.45	0.76	0.57
WSW	3.50	2.29	0.78	0.67
SSW	4.47	2.58	0.78	0.57
SSE	4.02	2.81	1.01	0.74
ESE	5.41	5.00	0.99	0.86
ENE	2.90	1.93	0.89	0.78
NNE	2.53	2.58	0.56	0.65
24 HR RANGE (KM)				
<200	4.87	3.57	0.82	0.50
200-400	3.44	2.29	0.77	0.54
400-600	4.47	3.74	0.98	0.91
600-800	3.44	2.01	0.62	0.34
800-1000	3.44	2.40	0.78	0.77
1000-1200	2.12	1.31	0.40	0.40
1200-1400	2.89	1.70	0.40	0.21
SURFACE TRAJECTORY				
48 HR SECTOR				
NNW	2.75	2.04	0.55	0.33
WNW	2.91	2.67	0.78	0.59
WSW	4.13	2.94	0.94	0.76
SSW	5.32	2.57	0.89	0.49
SSE	4.02	1.89	0.90	0.76
ESE	3.47	1.94	0.65	0.42
ENE	4.03	4.65	0.90	0.70
NNE	3.76	4.36	0.92	1.17
48 HR RANGE (KM)				
<200	6.83	3.43	1.38	0.60
200-400	3.87	2.25	0.74	0.46
400-600	4.62	3.25	0.97	0.92
600-800	4.50	3.56	0.84	0.57
800-1000	3.03	2.43	0.81	0.69
1000-1200	2.42	1.74	0.66	0.51
1200-1400	2.17	1.55	0.49	0.18
1400-1600	2.60	2.03	0.47	0.38
1600-1800	1.70	0.84	0.22	0.05
1800-2000	0.30	0.11	0.01	0.00
2000-2200	2.05	--	1.17	--

	SO4 MEAN	SO4 SD	NO3 MEAN	NO3 SD
TYPE OF PRECIPITATION				
CONTINUOUS	2.94	2.19	0.74	0.58
CONVECTIVE	4.31	3.26	0.75	0.67
NATURE OF PRECIPITATION				
RAIN	4.28	3.92	0.69	0.57
SNOW	2.25	1.94	0.83	0.66
FREEZING	7.20	5.52	1.52	1.33
MIXED	2.65	2.37	0.56	0.58
PREDOMINANT CLOUDS				
TOWERING CUMULUS	3.64	2.94	0.55	0.56
ALTOCUMULUS	2.58	1.93	0.85	0.36
ALTOSTRATUS	2.33	1.20	0.35	0.16
CUMULONIMBUS	4.28	1.84	0.59	0.29
CUMULUS	3.33	2.73	0.88	0.65
NIMBOSTRATUS	2.83	2.05	0.49	0.35
STRATOCUMULUS	3.52	3.13	0.79	0.60
STRATUS	5.88	3.51	1.43	1.12
SURFACE WIND SECTOR				
CALM	2.05	0.78	0.30	0.09
NNW	2.74	1.50	0.56	0.44
WNW	3.57	3.17	0.82	0.87
WSW	3.20	2.45	0.85	0.61
SSW	4.26	2.18	0.78	0.46
SSE	4.82	3.50	0.69	0.43
ESE	3.89	2.12	0.70	0.35
ENE	3.46	3.95	1.10	1.03
NNE	2.19	1.60	0.48	0.35
850 MB WIND SECTOR				
NNW	3.17	3.01	0.79	0.87
WNW	3.45	2.73	0.79	0.71
WSW	4.30	2.70	0.78	0.48
SSW	3.97	2.68	0.80	0.69
SSE	3.27	2.87	0.38	0.13
ESE	5.48	6.46	1.22	1.66
ENE	1.91	1.50	0.48	0.29
NNE	5.13	3.87	0.67	0.70

Appendix E

Table E1: The frequency distribution of the categorical variables for the top 30% of the SO_4 and NO_3 readings.

	SO4 NO	SO4 PCT	NO3 NO	NO3 PCT
SYNOPTIC TYPE				
WARM FRONT	13	24	12	23
COLD FRONT	14	25	10	19
STATIONARY FRONT	9	16	6	11
OCCLUDED LOW	7	12	14	26
COLD LOW	1	2	2	4
AIRMASS	6	11	5	9
WARM AND COLD FRONT	5	9	4	8
TRACK OF LOW				
ALBERTA LOW	18	33	17	32
COLORADO LOW	30	55	22	42
TEXAS LOW NORTH	2	4	3	6
TEXAS LOW SOUTH	1	2	4	8
GREAT LAKES	4	7	7	13
AIRMASS				
CA	5	9	12	23
CMA	0	0	0	0
MA	1	2	1	2
MP	2	4	1	2
MT	0	0	0	0
CA CMA	1	2	2	4
CA MA	11	20	13	25
CMA MA	7	13	9	17
MA MP	17	31	10	19
MP MT	11	20	5	9

	SO4		NO3	
	NO	PCT	NO	PCT
850 MB TRAJECTORY				
24 HR SECTOR				
NNW	3	6	2	4
WNW	16	30	19	37
WSW	28	52	25	48
SSW	7	13	5	10
ENE	0	0	1	2
24 HR RANGE (KM)				
<200	1	2	3	6
200-400	20	37	16	31
400-600	7	13	6	12
600-800	13	24	11	21
800-1000	5	9	8	15
1000-1200	2	4	5	10
1200-1400	3	6	3	6
1400-1600	2	4	0	0
1600-1800	1	2	0	0
48 HR SECTOR				
NNW	5	9	3	6
WNW	14	26	19	37
WSW	28	53	24	47
SSW	6	11	5	10
48 HR RANGE (KM)				
<200	1	2	2	4
200-400	3	6	3	6
400-600	4	7	3	6
600-800	11	20	9	17
800-1000	7	13	5	10
1000-1200	6	11	7	1 3
1200-1400	3	6	4	8
1400-1600	7	13	6	12
1600-1800	6	11	6	12
1800-2000	5	9	5	10
2000-2200	1	2	2	4

	SO4 NO	SO4 PCT	NO3 NO	NO3 PCT
SURFACE TRAJECTORY				
24 HR SECTOR				
NNW	2	4	3	6
WNW	7	14	5	10
WSW	10	20	8	17
SSW	14	29	12	25
SSE	5	10	6	13
ESE	7	14	6	13
ENE	2	4	5	10
NNE	2	4	3	6
24 HR RANGE (KM)				
<200	11	22	10	21
200-400	11	22	11	23
400-600	14	29	15	31
600-800	7	14	5	10
800-1000	5	10	6	13
1000-1200	0	0	1	2
1200-1400	1	2	0	0
SURFACE TRAJECTORY				
48 HR SECTOR				
NNW	5	11	2	5
WNW	3	7	5	11
WSW	10	22	12	27
SSW	14	31	9	20
SSE	4	9	4	9
ESE	3	7	2	5
ENE	3	7	6	14
NNE	3	7	4	9
48 HR RANGE (KM)				
<200	7	16	6	14
200-400	7	16	6	14
400-600	11	24	8	18
600-800	11	24	11	25
800-1000	5	11	9	20
1000-1200	1	2	2	5
1200-1400	1	2	0	0
1400-1600	2	4	1	2
2000-2200	0	0	1	2

	SO4		NO3	
	NO	PCT	NO	PCT
TYPE OF PRECIPITATION				
CONTINUOUS	16	36	25	54
CONVECTIVE	28	64	21	46
NATURE OF PRECIPITATION				
RAIN	35	80	22	48
SNOW	6	14	21	46
FREEZING	1	2	1	2
MIXED	2	5	2	4
PREDOMINANT CLOUDS				
TOWERING CUMULUS	2	5	1	2
ALTOCUMULUS	0	0	1	2
CUMULONIMBUS	8	18	3	7
CUMULUS	4	9	6	13
NIMBOSTRATUS	5	11	3	7
STRATOCUMULUS	17	39	25	54
STRATUS	8	18	7	15
SURFACE WIND SECTOR				
NNW	3	6	2	4
WNW	9	18	8	17
WSW	8	16	11	23
SSW	10	20	11	23
SSE	11	22	5	10
ESE	4	8	4	8
ENE	3	6	5	10
NNE	1	2	2	4
850 MB WIND SECTOR				
NNW	4	8	5	11
WNW	13	25	12	26
WSW	24	46	20	43
SSW	8	15	7	15
SSE	1	2	0	0
ESE	1	2	1	2
ENE	0	0	0	0
NNE	1	2	1	2

Appendix F

TABLE OF TR5 BY TY1

TR5 / TY1 — FREQUENCY / PERCENT / ROW PCT / COL PCT	.	CONTIN	CNVTV	TOTAL
.	0 . . .	1 . . .	2 . . .	. .
NNW	1 . . .	0 0.00 0.00 0.00	4 6.35 100.00 8.89	4 6.35
WNW	1 . . .	1 1.59 16.67 5.56	5 7.94 83.33 11.11	6 9.52
WSW	2 . . .	4 6.35 28.57 22.22	10 15.87 71.43 22.22	14 22.22
SSW	5 . . .	5 7.94 26.32 27.78	14 22.22 73.68 31.11	19 30.16
SSE	0 . . .	1 1.59 50.00 5.56	1 1.59 50.00 2.22	2 3.17
ESE	1 . . .	1 1.59 14.29 5.56	6 9.52 85.71 13.33	7 11.11
ENE	1 . . .	4 6.35 100.00 22.22	0 0.00 0.00 0.00	4 6.35
NNE	1 . . .	2 3.17 28.57 11.11	5 7.94 71.43 11.11	7 11.11
TOTAL	. .	18 28.57	45 71.43	63 100.00

Table F1. Contingency table between precipitation type (TY1) and surface 24 hour sector (TR5) for warm months.

TABLE OF TR8 BY ISN

TR8 ISN

TR8 (FREQUENCY / PERCENT / ROW PCT / COL PCT)	WARM FNT	COLD FNT	STNRY FNT	OCCLUDED LOW	COLD LOW	AIRMASS	WARM AND COLD FN	TOTAL
.	2	2	0	3	0	0	2	.
	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	
	.	.	.	.	.	.	.	
200 KM	2	1	2	0	0	1	0	6
	2.86	1.43	2.86	0.00	0.00	1.43	0.00	8.57
	33.33	16.67	33.33	0.00	0.00	16.67	0.00	
	22.22	6.25	16.67	0.00	0.00	9.09	0.00	
400 KM	3	5	4	4	0	2	1	19
	4.29	7.14	5.71	5.71	0.00	2.86	1.43	27.14
	15.79	26.32	21.05	21.05	0.00	10.53	5.26	
	33.33	31.25	33.33	25.00	0.00	18.18	33.33	
600 KM	4	4	3	2	1	0	1	15
	5.71	5.71	4.29	2.86	1.43	0.00	1.43	21.43
	26.67	26.67	20.00	13.33	6.67	0.00	6.67	
	44.44	25.00	25.00	12.50	33.33	0.00	33.33	
800 KM	0	5	3	5	1	1	1	16
	0.00	7.14	4.29	7.14	1.43	1.43	1.43	22.86
	0.00	31.25	18.75	31.25	6.25	6.25	6.25	
	0.00	31.25	25.00	31.25	33.33	9.09	33.33	
TOTAL	9	16	12	16	3	11	3	70
	12.86	22.86	17.14	22.86	4.29	15.71	4.29	100.00

Table F2. Contingency table between synoptic type (ISN) and surface 48 hour range (TR8) for warm months.

SAS

Table F2. cont'd

TABLE OF TPB BY ISN

TPB ISN

FREQUENCY / PERCENT / ROW PCT / COL PCT	WARM FNT	COLD FNT	STNRY FNT	OCCLUDED LOW	COLD LOW	AIRMASS	WARM AND COLD FN	TOTAL
1000 KM	0	0	0	2	0	4	0	6
	0.00	0.00	0.00	2.86	0.00	5.71	0.00	8.57
	0.00	0.00	0.00	33.33	0.00	66.67	0.00	
	0.00	0.00	0.00	12.50	0.00	36.36	0.00	
1200 KM	0	1	0	1	0	1	0	3
	0.00	1.43	0.00	1.43	0.00	1.43	0.00	4.29
	0.00	33.33	0.00	33.33	0.00	33.33	0.00	
	0.00	6.25	0.00	6.25	0.00	9.09	0.00	
1400 KM	0	0	0	0	1	0	0	1
	0.00	0.00	0.00	0.00	1.43	0.00	0.00	1.43
	0.00	0.00	0.00	0.00	100.00	0.00	0.00	
	0.00	0.00	0.00	0.00	33.33	0.00	0.00	
1600 KM	0	0	0	0	0	2	0	2
	0.00	0.00	0.00	0.00	0.00	2.86	0.00	2.86
	0.00	0.00	0.00	0.00	0.00	100.00	0.00	
	0.00	0.00	0.00	0.00	0.00	18.18	0.00	
1900 KM	0	0	0	2	0	0	0	2
	0.00	0.00	0.00	2.86	0.00	0.00	0.00	2.86
	0.00	0.00	0.00	100.00	0.00	0.00	0.00	
	0.00	0.00	0.00	12.50	0.00	0.00	0.00	
TOTAL	9	16	12	16	3	11	3	70
	12.86	22.86	17.14	22.86	4.29	15.71	4.29	100.00

SAS

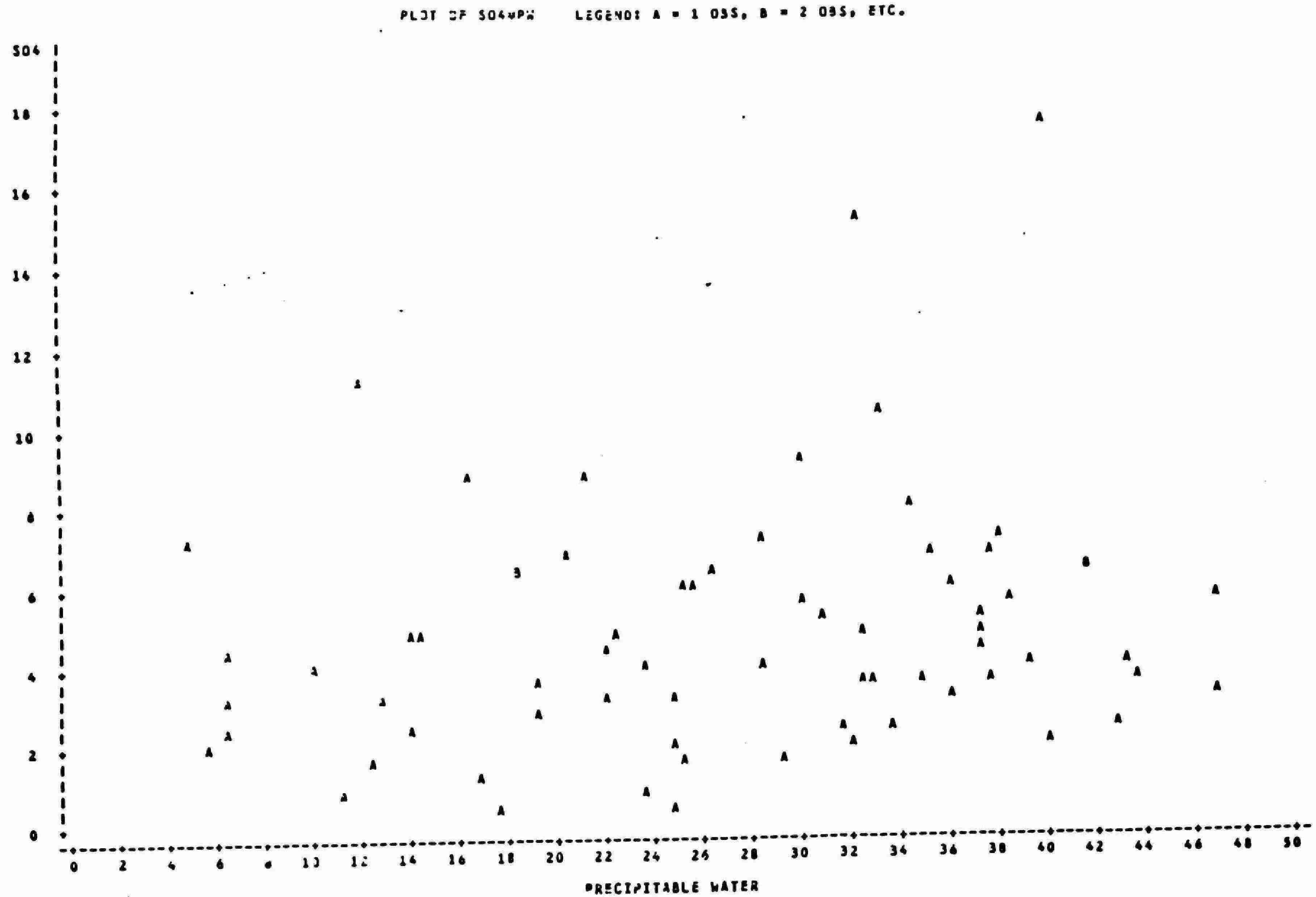
TABLE OF TY3 BY TR1

TY3 TR1

TY3 FREQUENCY PERCENT ROW PCT COL PCT	.	NNW	WNW	WSW	SSW	NNE	TOTAL
.	1	1	3	3	5	0	.
	.	.	.	.	.	.	.
	.	.	.	.	.	.	
	.	.	.	.	.	.	
AC	0	0	0	0	0	1	1
	.	0.00	0.00	0.00	0.00	1.11	1.11
	.	0.00	0.00	0.00	0.00	100.00	
	.	0.00	0.00	0.00	0.00	100.00	
AS	0	0	1	2	0	0	3
	.	0.00	1.11	2.22	0.00	0.00	3.33
	.	0.00	33.33	66.67	0.00	0.00	
	.	0.00	5.00	5.26	0.00	0.00	
CS	0	0	0	1	2	0	3
	.	0.00	0.00	1.11	2.22	0.00	3.33
	.	0.00	0.00	33.33	66.67	0.00	
	.	0.00	0.00	2.63	9.52	0.00	
CU	0	4	3	2	0	0	9
	.	4.44	3.33	2.22	0.00	0.00	10.00
	.	44.44	33.33	22.22	0.00	0.00	
	.	40.00	15.00	5.26	0.00	0.00	
NS	1	0	0	10	11	0	21
	.	0.00	0.00	11.11	12.22	0.00	23.33
	.	0.00	0.00	47.62	52.38	0.00	
	.	0.00	0.00	26.32	52.38	0.00	
SC	0	6	12	17	5	0	40
	.	6.67	13.33	18.89	5.56	0.00	44.44
	.	15.00	30.00	42.50	12.50	0.00	
	.	60.00	60.00	44.74	23.81	0.00	
ST	0	0	4	6	3	0	13
	.	0.00	4.44	6.67	3.33	0.00	14.44
	.	0.00	30.77	46.15	23.08	0.00	
	.	0.00	20.00	15.79	14.29	0.00	
TOTAL	.	10	20	38	21	1	90
	.	11.11	22.22	42.22	23.33	1.11	100.00

Table F3. Contingency table between cloud type (TY3)and 850 mb 24 hour sector (TR1) for cold months.

Figure F1. SO_4 versus precipitable water for warm months.



NOTE: 9 OBS HAD MISSING VALUES

Figure F2. SO_4 versus duration of precipitation for warm months.

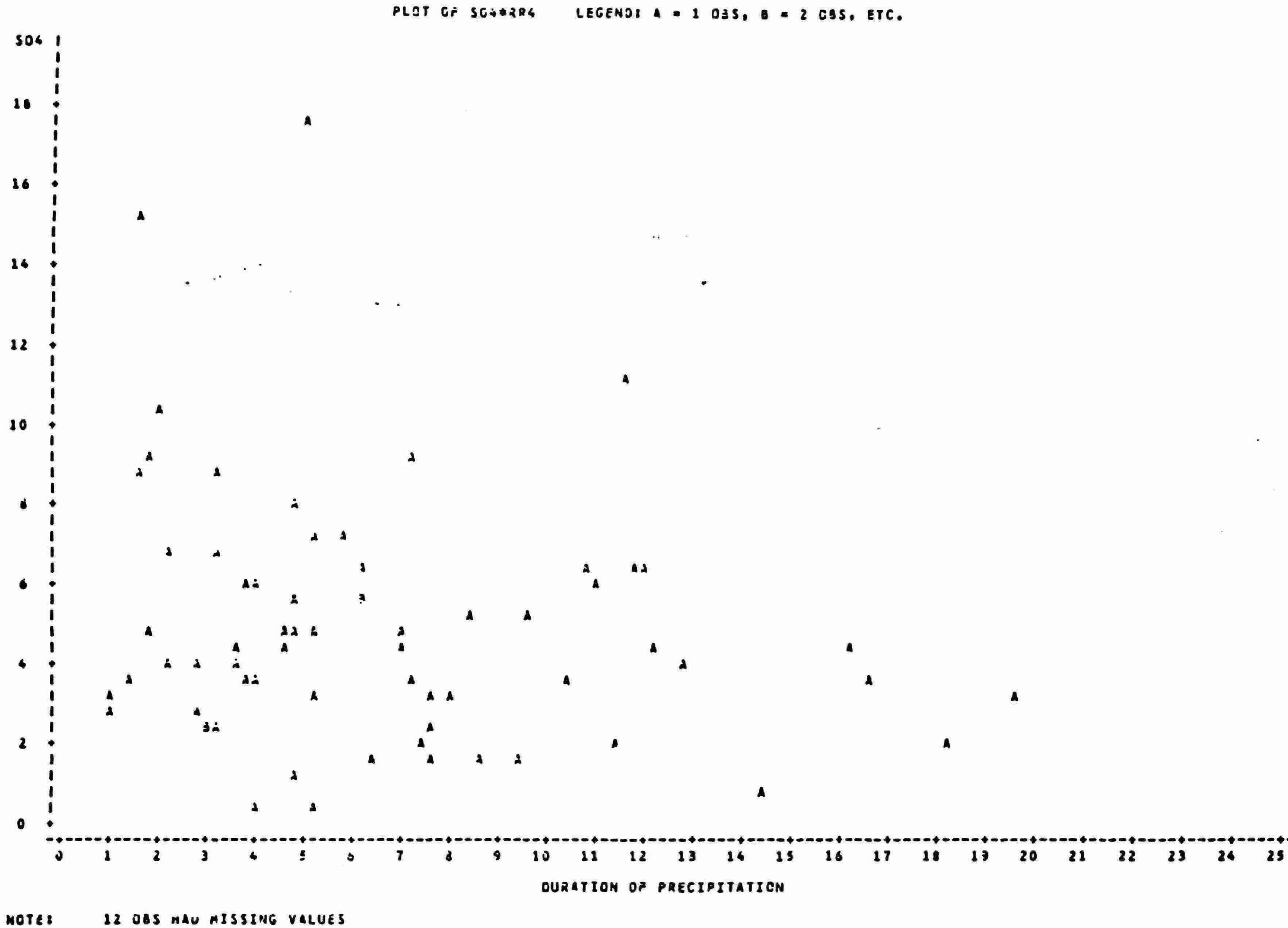
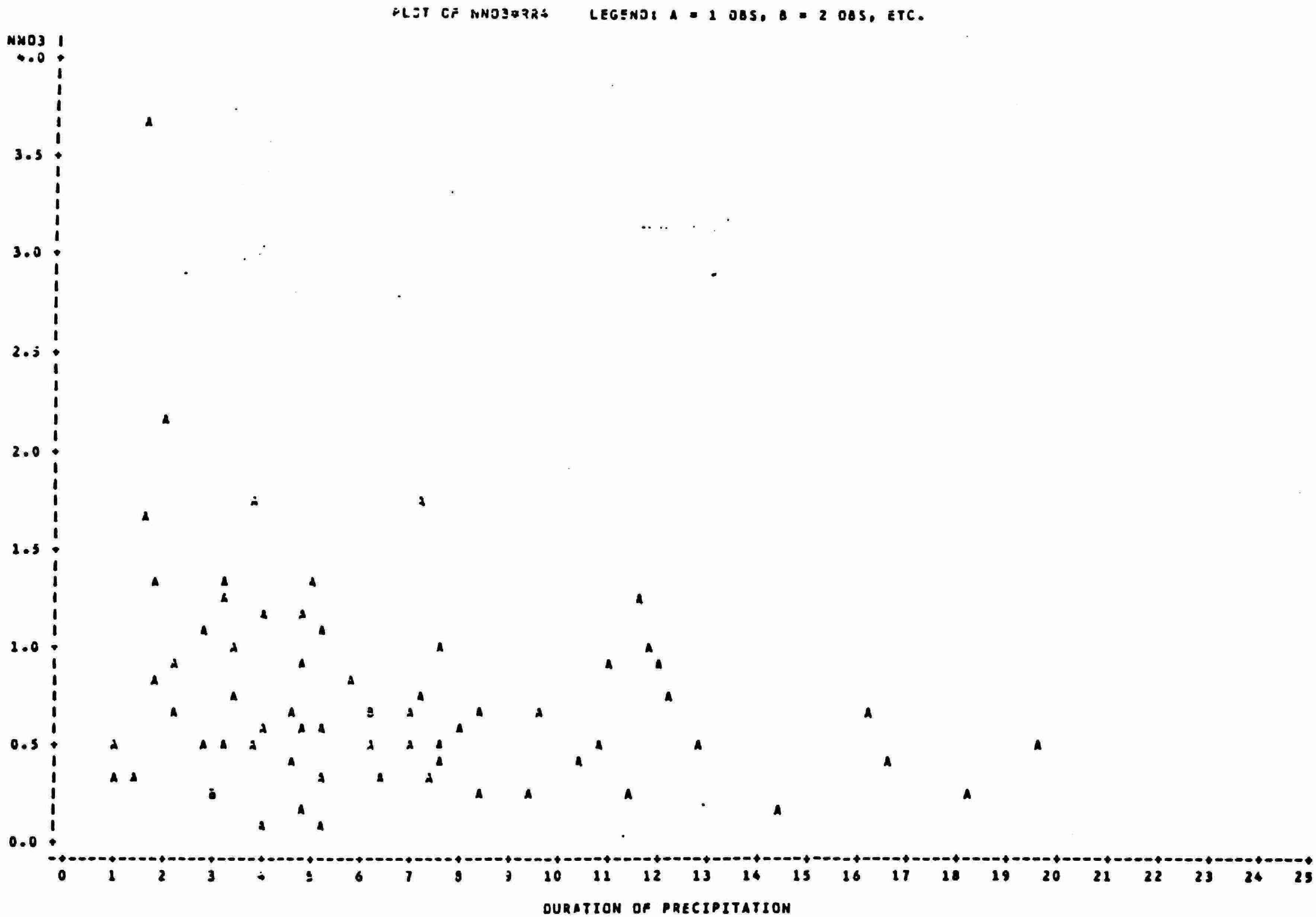


Figure F3. NO_3 versus duration of precipitation for warm months.



NOTE: 12 OBS HAD MISSING VALUES

Figure F4. NO_3 versus amount of precipitation for warm months.

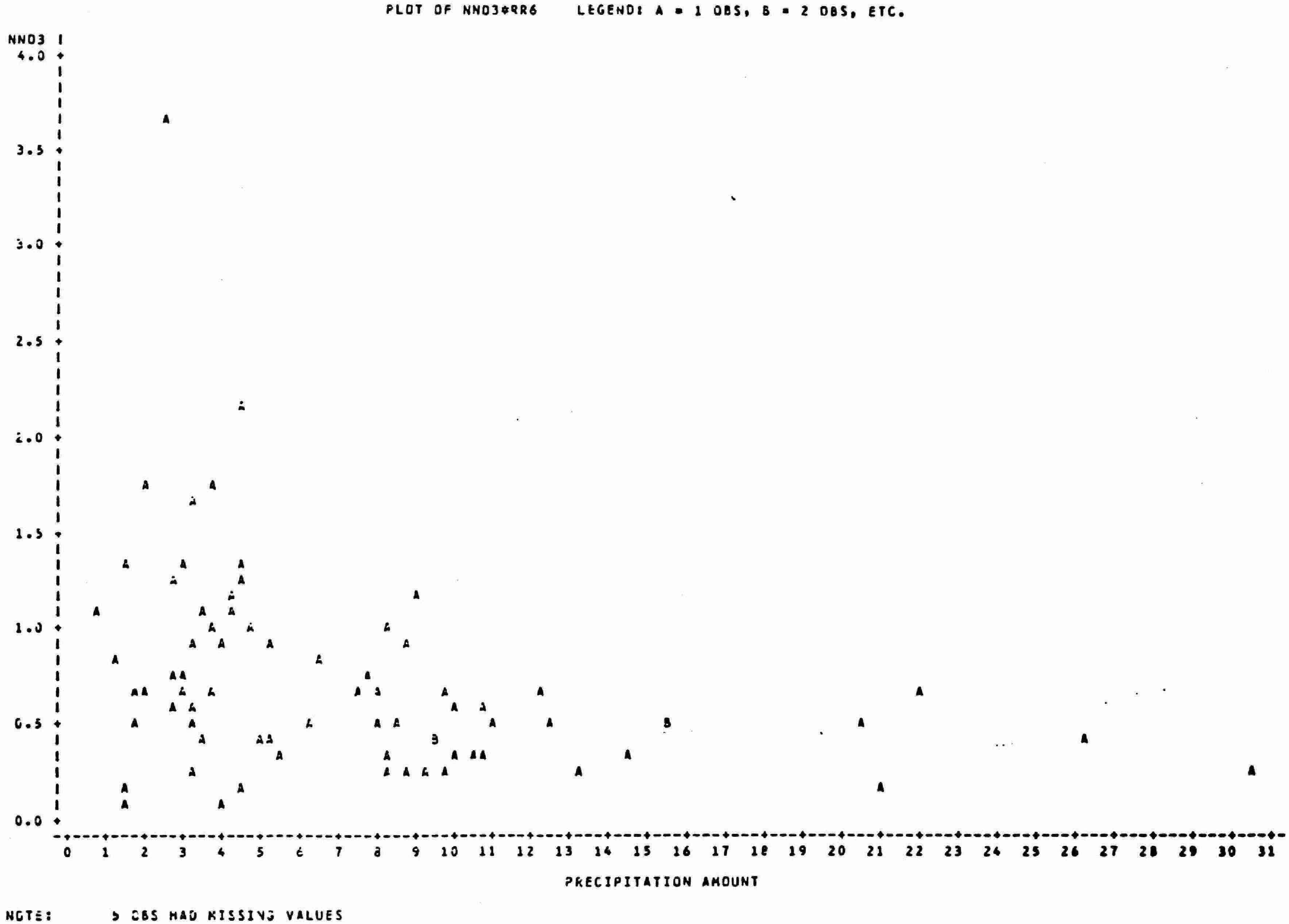


Figure F5. SO_4 versus cloud base height for cold months.

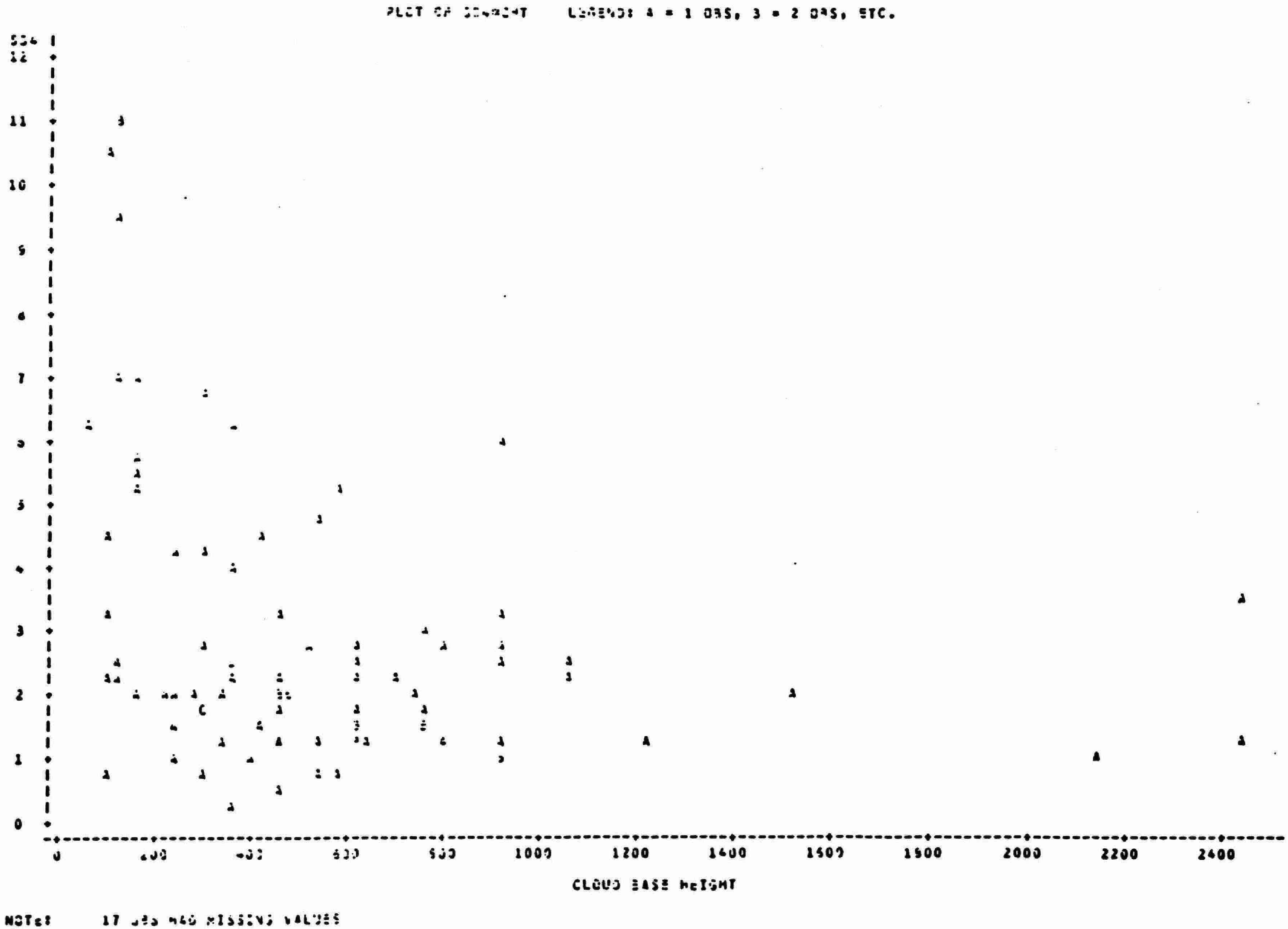


Figure F6. SO_4 versus amount of precipitation for cold months.

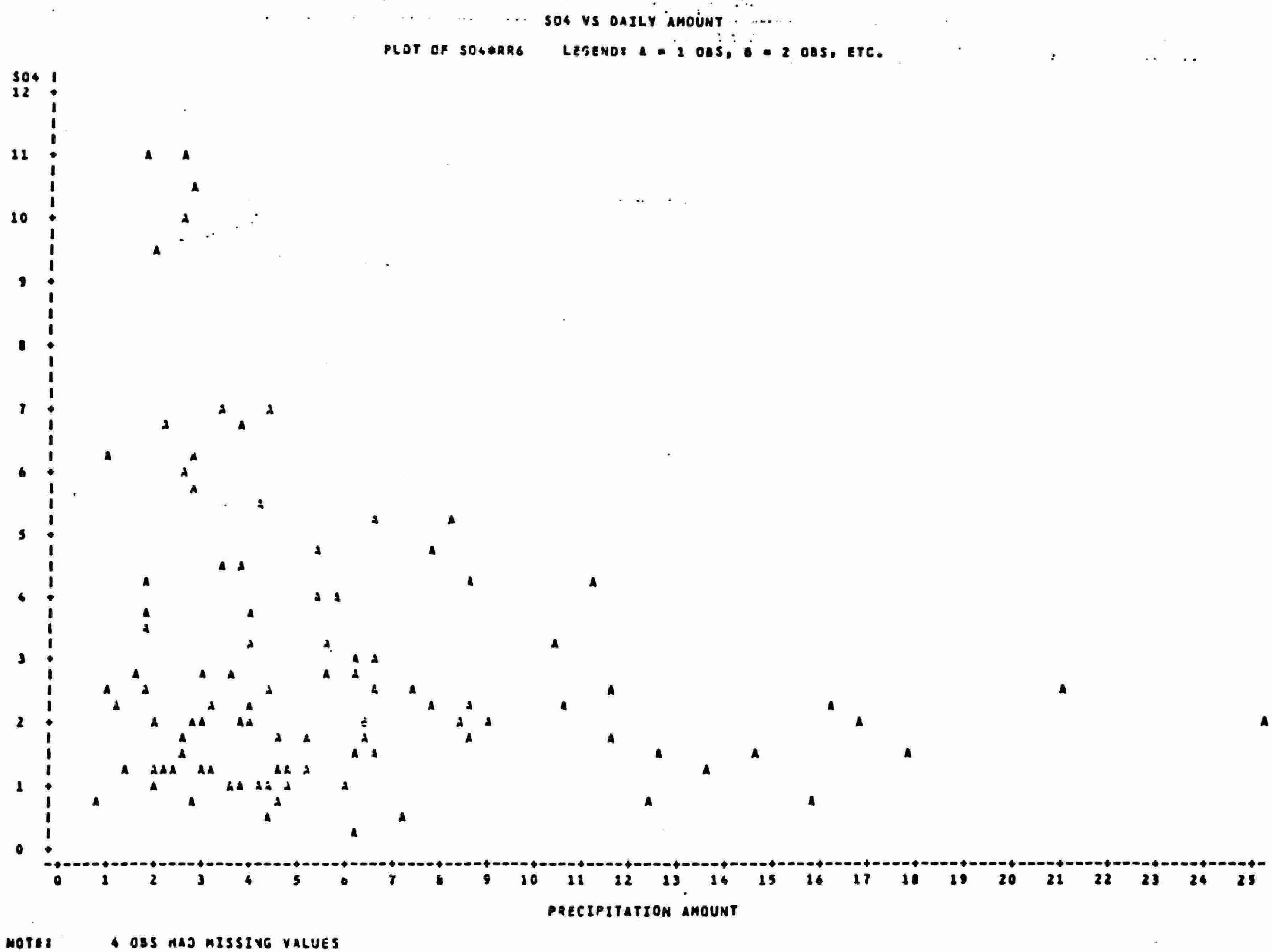
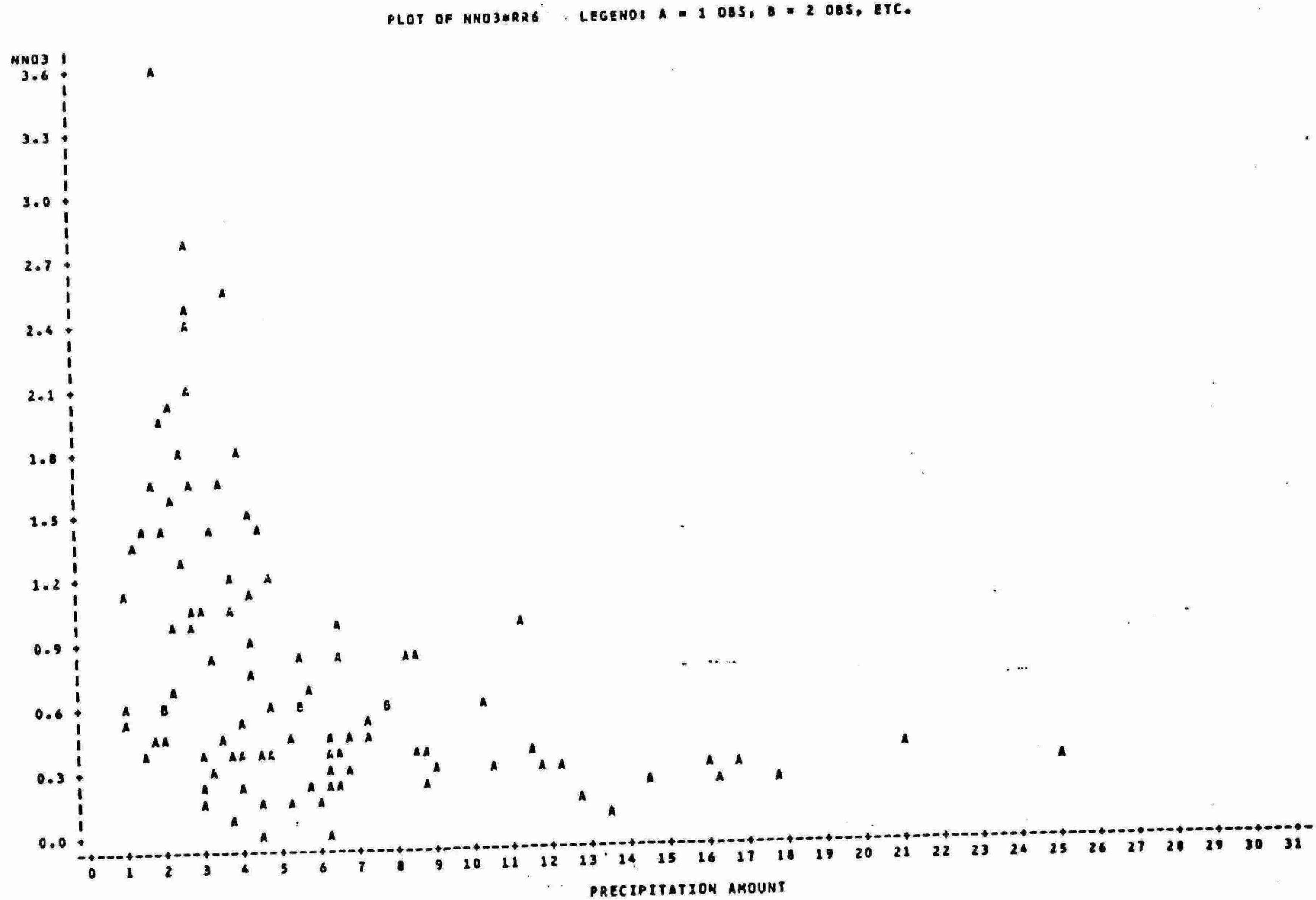


Figure F7: NO_3 versus amount of for cold months.



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Addendum to the Final Report on the Determination of APIOS Precipitation Chemistry from the Climatology of Regional Precipitation Episodes

prepared for the Ontario Ministry of the Environment

by D.R. Hudak and T.B. Low

of the KelResearch Corporation

September, 1986

Table of Contents for Addendum

8. Introduction to Addendum

The 1983 meteorological data for the four regions were analysed in the same way as the 1982 data. However the following variables were not analysed as they showed no promise in the previous analyses of being significantly correlated with the SO_4 or NO_3 measurements:

- track of the low
- cloud top height
- cloud thickness
- rainfall rate (mm/15 min)
- rainfall rate (mm/30 min)
- rainfall rate (mm/hr)
- maximum 6 hr amount

The abstracted data were then transferred to the MOE computer. The format was the same as that of the previous year except that the order of the 850 mb trajectories and the surface trajectories was interchanged.

The purpose of this analysis was to check on the lack of positive results found from the 1982 data as contained in the main report entitled Final Report on the Determination of APIOS Precipitation Chemistry from the Climatology of Regional Precipitation Episodes, July 1986 (referred to as Kell). If the problem was due to an insufficient amount of data, then the results should improve with an additional year's analysis. Otherwise, the basic problem would be in the quality of the data for the problem at hand.

In this report, the 1983 data will firstly be examined in relation to the 1982 data to ensure that it can serve as a useful supplement to the data base. Then the relationships between the SO_4 and the NO_3 readings and the meteorological variables for 1983, and 1982-83 will be carried out. Finally, the statistical model developed in Kell will be tested for the 1982-83 data set and subsequent results from experiments in forecasting annual deposition from a selected sample of days for both years will be presented.

9. Acidic Precipitation Data for 1983

Table 9.1 gives the SO_4 and NO_3 averages, by region, for 1983.

Table 9.1: SO_4 and NO_3 averages by region.

	SW	CE	SE	NW
NO OF OBS	137	153	132	131
MEAN SO_4 (mg/l)	3.30	2.88	3.05	1.24
MEAN NO_3 (mg/l)	0.61	0.59	0.57	0.22

A comparison of Table 9.1 with the SO_4 and NO_3 values in Table C1 of Kell reveals that there were 10% to 15% fewer observations in 1983. This was particularly noticeable in the southwest where the number of observations dropped from 183 to 137. The means of the SO_4 measurements were somewhat lower in 1983 but relative positions of the values in the 4 regions remained the same. Duncan's Multiple Range Test (procedure ANOVA in SAS User's Guide: Statistics 1982 Edition) indicated that the northwest readings were significantly different from the other 3 but the remaining 3 regions were not significantly different from each other. The means of the NO_3 measurements were almost exactly the same in 1983 as in 1982 with only the southwest region being slightly lower. Duncan's Multiple Range Test showed that the northwest readings were significantly different from the other 3 regions, which in turn were not statistically significant from each other. But statistical tests of the averages of the 2 years showed that there is no statistically significant difference in the readings in the 4 regions between the 1982 and 1983.

Table 9.2 gives the monthly variation in the SO_4 and NO_3 readings in the southwest region for 1983.

Table 9.2: Monthly averages in the southwest region for 1983.

MONTH	SO_4 (mg/l)	NO_3 (mg/l)
JANUARY	3.96	1.12
FEBRUARY	3.66	0.84
MARCH	3.89	0.89
APRIL	3.48	0.66
MAY	3.38	0.46
JUNE	3.72	0.50
JULY	3.34	0.55
AUGUST	4.41	0.70
SEPTEMBER	3.30	0.50
OCTOBER	2.80	0.37
NOVEMBER	2.48	0.45
DECEMBER	2.14	0.48

The average of the SO_4 values for the warmer months (April to September) was 3.58 mg/l while for the colder months it was 3.01 mg/l. When these seasonal differences were tested for statistical significance (procedure ANOVA in SAS User's Guide: Statistics 1982 Edition), the F value was 3.22 and the significance probability was 0.08. In other words, the differences by season were not different at the 0.05 level. A further examination reveals that the very high values in May, June, and July in 1982 were not seen in 1983.

The mean for the NO_3 readings in the warmer months was 0.66 mg/l and in the colder months 0.57 mg/l. An F value of 1.37 and significance probability of 0.25 reveal that there was no significant difference in the seasonal readings

of the NO_3, as was found also to be the case in 1982. With the exception that some of the very high readings in 1982 were not seen in 1983, the SO_4 and NO_3 measurements in 1983 appear to be comparable with the 1982 readings.

10. Meteorological Data for 1983

Appendix G of this addendum summarizes the 1983 data for the 4 regions. For the southwest region the analysis of variance was performed on the meteorological data to see if there was any difference in the data between 1982 and 1983. Table 10.1 summarizes the variables which showed a statistically significant difference in their values between the 2 years at the 10% significance level.

Table 10.1: Variables which had statistically significant differences (at the 10% level) between 1982 and 1983 for the southwest region.

VARIABLE	P>F	REASON
surface temperature	0.01	1983 was 3.0°C warmer
surface dewpoint	0.01	1983 was 2.9°C warmer
precipitable water	0.05	1983 was 3.0 mm higher
total totals index	0.04	1983 was 4.6 higher
% of stns with rain	0.0001	1983 was 10% higher
airmass	0.09	more mT mP air and less cA and cmA air in 1983
nature of pcpn	0.002	less snow and more rain in 1983
surface wind dir	0.02	more easterly winds in 1983
850 mb wind dir	0.04	more easterly winds in 1983

From Table 10.1, the differences between the 2 years meteorologically when precipitation was recorded at the APIOS stations could be characterized in the following terms. In 1983, conditions were warmer and more moist with the rain being more widespread than in 1982. The warmer airmasses (mT, mP) were more in evidence in 1983. Also, there were more easterly winds during the precipitation in 1983 than 1982.

11. A Comparison between SO_4, NO_3 and the Meteorological Variables for 1983

For the discrete meteorological variables, Table H1 in Appendix H summarizes the SO_4 and NO_3 data as a function of the discrete categories while Table I1 in Appendix I gives the frequency distribution of the categorical variables for the top 30% of the SO_4 and NO_3 readings. When compared with the results of 1982 (Table 4.3 c in Kel1) some of the findings were not substantiated in 1983. In particular, the characterization of high SO_4 episodes with stationary fronts and stratus clouds was not seen in 1983. For the NO_3

readings, the high values associated with snowfall, the cA, cmA, and mA airmasses, and stratus clouds in 1982 were not seen in the 1983 data.

Table H2 gives the correlation coefficients and significance probabilities between the SO_4 and NO_3 values and the continuous meteorological variables while Table I2 gives the averages and standard deviations of the continuous meteorological variables for the top 30% readings of the SO_4 and the NO_3. Inspection of these tables reveals that cloud base height and the duration of the precipitation were not related to variations in SO_4 and NO_3 in the same way as in 1982 when lower clouds base heights and lower durations were associated with high values of SO_4 and NO_3.

Combining the 2 years data, high episodes of SO_4 and NO_3 can be characterized by the meteorological conditions as given in Table 11.1. In order for a factor to be considered to be important, the mean of the SO_4 or NO_3 readings for that category had to be the highest or second highest among the means for all the categories for that variable. Also, the frequency (in percentage) of that factor had to increase when considering the top 30% of the SO_4 or NO_3 readings as compared to the frequency in the whole data set.

Table 11.1: Meteorological conditions associated with high episodes of SO_4 and NO_3 as derived from an inspection of the tables in Appendix G, H, I of this addendum and their counterparts, namely Appendix C, D, E, and Tables 4.6 and 4.7 of Kell.

SO_4	NO_3
warm fronts	
850 mb trajectories originating in the WSW	850 mb trajectories originating in the WSW
24 hr 850 mb trajectory ranges less than 400 km	24 hr 850 mb trajectory ranges less than 400 km
24 hr surface trajectories originating in the SSW to ESE	24 hr surface trajectories originating in the SSW to ESE
convective situations	
rain	
surface and 850 mb winds from the WSW to SSE	
mT and mP air	
high surface temperatures, dewpoints, precipitable water, totals index	low surface temperatures, dewpoints wind speeds,rainfall amounts, and area of pcpn
low winds speeds, rainfall amounts, and area of pcpn	

12. Statistical Tests Between SO_4, NO_3 and the Meteorological Variables

An analysis of variance was done between SO_4 and NO_3 and the discrete meteorological variables for the 1983 data set (Table 12.1). The data were divided into warm and cold months, as before. The underlined values indicate those variables whose significance probability was 0.10 or less. A comparison between Table 12.1 with Table 4.4 in Kell reveals that the variables which were significant from one year to the next were not the same ones. For the SO_4 readings, the variables which were significant for both years were, in the warm months, the 24 hr surface and 850 mb trajectory sectors and in the cold months, the nature of the precipitation. For the NO_3 measurements, only the 24 hr 850 mb trajectory range in the cold months was common to both analyses.

Table 12.2 summarizes the results for 1983 of the regressions between the SO_4 and NO_3 measurements and the continuous variables. In this case the only variables significant at the 10% level for both analyses were the cloud base height and the amount of precipitation with SO_4 in the cold months, and the amount of precipitation with NO_3. For the cloud base height, the slope estimate is also of a different sign for the 2 years.

These comparisons point out very sharply that an increase in the quantity of the data to 2 years is not going to help improve the results that were obtained with 1 year's data.

13. The Statistical Model

The statistical model based on the analysis of covariance for the 1982 data set was run using the combined 1982-83 data set for all 4 regions. In order to assess the possible improvement in the model's performance, the variables which were deemed best in the 1982 analysis were used. Tables 13.1 to 13.4 contain the results of the ANCOVA for the four regions. The significance probabilities (P>F) were very similar in the 2 analyses. However the amount of variance explained in the analyses (R) using the 1982-83 data set was substantially less than in the analyses with only the 1982 data. In the former one, R averaged 0.49 while in the latter it averaged 0.66. In all 16 cases, SO_4 and NO_3 for the warm and cold months for the 4 regions, R was less using the 1982-83 data set than using the 1982 data set. In 13 out of the 16 cases the mean square error was larger with the 1982-83 data set. This clearly suggests that having more data does not overcome the difficulties encountered in the first year analysis and that the relationship between the SO_4 and NO_3 measurements and the meteorological variables presented is not strong enough to be used effectively in a statistical model.

Table 12.1. An analysis of variance between SO_4 and NO_3 and the discrete variables for 1983. Given are the F statistic and the significance probability (P>F). Underlined values are those deemed significant enough to warrant further statistical testing.

SO_4

	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
synoptic type	2.00	<u>0.09</u>	1.04	0.40
airmass	1.57	0.17	1.71	0.12
850 mb 24 hr sector	4.54	<u>0.01</u>	1.53	0.18
range	0.33	0.89	1.03	0.41
48 hr sector	2.91	<u>0.03</u>	1.07	0.41
range	0.62	0.75	1.03	0.43
sfc 24 hr sector	3.11	<u>0.01</u>	0.42	0.88
range	1.29	0.28	0.85	0.56
48 hr sector	1.64	0.15	0.33	0.93
range	1.34	0.26	0.33	0.94
type of pcpn	1.49	0.23	3.06	<u>0.08</u>
nature of pcpn	3.33	<u>0.07</u>	4.82	<u>0.004</u>
cloud type	1.91	<u>0.09</u>	0.83	0.55
sfc wind dir	0.73	0.66	1.53	0.17
850 mb wind dir	2.36	<u>0.05</u>	1.29	0.27

NO_3

	WARM MONTHS		COLD MONTHS	
	F	P>F	F	P>F
synoptic type	1.70	0.15	0.71	0.62
airmass	2.06	<u>0.07</u>	0.66	0.71
850 mb 24 hr sector	2.10	0.11	0.41	0.89
range	0.59	0.71	2.23	<u>0.07</u>
48 hr sector	1.10	0.37	1.24	0.32
range	0.58	0.79	0.39	0.88
sfc 24 hr sector	1.94	<u>0.08</u>	0.32	0.94
range	0.36	0.87	0.53	0.81
48 hr sector	0.75	0.63	0.46	0.85
range	1.14	0.36	0.39	0.90
type of pcpn	0.78	0.38	2.58	0.11
nature of pcpn	2.54	0.12	0.22	0.88
cloud type	0.96	0.47	0.73	0.63
sfc wind dir	0.26	0.98	0.29	0.96
850 mb wind dir	1.46	0.22	0.71	0.67

Table 12.2: Slope estimate and significance probability between SO_4, NO_3, and the continuous meteorological variables for 1983.

SO_4

	warm months		cold months	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.0005	0.18	0.0015	0.07
SURFACE TEMPERATURE	0.047	0.21	0.054	0.32
SURFACE DEWPOINT	0.026	0.50	0.04	0.43
SURFACE WIND SPEED	-0.006	0.91	-0.14	0.03
850 MB TEMPERATURE	0.05	0.14	0.083	0.15
850 MB WIND SPEED	0.009	0.66	-0.004	0.86
PRECIPITABLE WATER	0.013	0.49	0.035	0.42
TOTAL TOTALS	0.012	0.39	0.019	0.36
DURATION OF PCPN	-0.07	0.25	0.035	0.01
AVERAGE RAINRATE mm/hr	-0.43	0.11	0.034	0.01
AMOUNT OF PCPN	-0.05	0.17	-0.14	0.03
% STNS WITH PCPN	-2.48	0.07	-0.71	0.61

NO_3

	warm months		cold months	
	b1	P>F	b1	P>F
CLOUD BASE HEIGHT	0.0001	0.19	0.0001	0.60
SURFACE TEMPERATURE	0.001	0.85	-0.002	0.84
SURFACE DEWPOINT	-0.001	0.85	-0.002	0.88
SURFACE WIND SPEED	-0.003	0.79	-0.03	0.01
850 MB TEMPERATURE	0.003	0.63	0.008	0.49
850 MB WIND SPEED	0.004	0.36	-0.003	0.55
PRECIPITABLE WATER	-0.0009	0.80	0.001	0.89
TOTAL TOTALS	-0.003	0.22	0.003	0.38
DURATION OF PCPN	-0.01	0.36	0.009	0.0001
AVERAGE RAINRATE mm/hr	-0.95	0.07	0.008	0.0001
AMOUNT OF PCPN	-0.02	0.02	-0.02	0.06
% STNS WITH PCPN	-0.67	0.01	-0.12	0.65

Table 13.1: Results of the ANCOVA for the Southwest Region for 1982-83.

WARM MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
		SO_4				
type of pcpn	6.17	0.02	3.38	0.0001	0.42	4.44
sfc 24 hr sector	4.97	0.0001				
interaction	2.15	0.05				
precipitable water	0.97	0.32				
duration of pcpn	0.56	0.46				
		NO_3				
synoptic type	2.47	0.03	1.62	0.04	0.47	0.14
sfc 48 hr range	1.31	0.26				
interaction	1.48	0.11				
duration of pcpn	2.10	0.15				
amount of pcpn	1.42	0.24				

COLD MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
		SO_4				
cloud type	3.13	0.005	4.87	0.0001	0.53	2.28
850 24 hr sector	2.64	0.014				
interaction	5.95	0.0001				
cloud base height	0.90	0.34				
amount of pcpn	24.67	0.0001				
		NO_3				
cloud type	3.03	0.006	5.65	0.0001	0.57	0.17
850 24 hr sector	4.58	0.0002				
interaction	6.54	0.0001				
cloud base height	0.25	0.62				
amount of pcpn	27.1	0.0001				

Table 13.2: Results of the ANCOVA for the Central Region for 1982-83.

WARM MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
		SO_4				
type of precipitation	7.58	0.007	3.00	0.0004	0.32	5.04
sfc 48 hr sector	4.98	0.0001				
interaction	0.30	0.937				
duration of precipitation	3.35	0.070				
sfc temperature	0.41	0.526				
		NO_3				
sfc 48 hr sector	4.71	0.001	2.41	0.001	0.51	0.08
850 wind direction	3.68	0.002				
interaction	1.52	0.107				
duration of pcpn	0.37	0.544				
sfc wind speed	0.12	0.729				

COLD MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
		SO_4				
airmass	2.41	0.026	1.95	0.0033	0.48	4.36
sfc 48 hr sector	1.82	0.104				
interaction	1.92	0.008				
sfc temperature	0.37	0.545				
		NO_3				
sfc 48 hr sector	3.39	0.003	4.24	0.0001	0.49	0.33
nature of pcpn	1.91	0.115				
interaction	5.14	0.0001				
cloud base height	0.22	0.640				
pcpn amount	14.54	0.0002				

Table 13.3: The ANCOVA for Southeast region for 1982-83.

WARM MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
		SO_4				
850 wind direction	3.70	0.003	2.59	0.001	0.56	4.24
sfc 48 hr sector	4.38	0.005				
interaction	1.55	0.110				
duration of pcpn	0.78	0.380				
sfc wind speed	1.88	0.175				
		NO_3				
synoptic type	1.02	0.428	3.11	0.0001	0.65	0.07
sfc 48 hr range	5.21	0.0002				
interaction	3.31	0.0001				
duration of pcpn	0.13	0.718				
amount of pcpn	3.16	0.080				

COLD MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
		SO_4				
nature of pcpn	4.45	0.0002	3.79	0.0001	0.50	2.24
sfc 24 hr sector	3.46	0.019				
interaction	3.70	0.0001				
sfc temperature	1.66	0.201				
		NO_3				
850 24 hr sector	2.81	0.014	2.22	0.005	0.31	0.39
nature of pcpn	0.57	0.639				
interaction	0.85	0.575				
precipitable water	4.43	0.038				
amount of pcpn	13.8	0.0003				

Table 13.4: Results of ANCOVA for northwest region for 1982-83.

WARM MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
	SO_4					
sfc 48 hr range	4.15	0.0001	2.54	0.0004	0.54	0.76
airmass	5.12	0.0001				
interaction	0.94	0.538				
cloud base height	0.00	0.988				
sfc temperature	1.84	0.179				
		NO_3				
airmass	5.07	0.0001	2.35	0.0003	0.54	0.02
sfc 48 hr sector	2.10	0.052				
interaction	1.59	0.052				
stns with pcpn	1.72	0.193				
sfc temperature	1.31	0.256				

COLD MONTHS

VARIABLE	F	P>F	F	P>F	R	E^2
		SO_4				
sfc 24 hr range	3.55	0.003	1.77	0.033	0.561	0.69
synoptic type	2.13	0.065				
interaction	0.77	0.714				
sfc temperature	0.10	0.749				
precipitable water	4.84	0.032				
		NO_3				
airmass	2.61	0.027	1.60	0.075	0.44	0.03
850 48 hr sector	1.42	0.226				
interaction	0.99	0.469				
pcpn amount	3.97	0.052				

14.0 Annual Deposition Prediction Results

Using the statistical model developed in the Section 13, predictions of annual deposition using the weighted average approach for regional averages of SO_4 and NO_3 were made for both years. The days used for the selected sample in the 1982 analysis were exactly the same as those used in Kell. For 1983 the following days were used for the selected sample:

	NO. of DAYS
January 10-14,29-31	8
February 1-6	6
March 18-21	4
April 6-17,28-30	15
May 1-4	4
June 3-6	4
July 28-31	4
August 8-11	4
September 15-23	9
October 11-14	4
November 27-30	4
December 3-7	5

Table 14.1 and 14.2 give the results of the deposition prediction for 1982 and 1983 respectively. As in Kell, two predictions were made for annual deposition. Prediction One (P1) was based on the categorizations of the statistical model while Prediction Two (P2) was made assuming no categorizations. Table 14.3 gives the absolute fractional errors associated with the deposition statistics. Overall, the errors were 10 to 15% in the predictions with approximately one-third of the days being sampled. In keeping with the results of Kell, P1 did not perform noticeably better than P2 for the data as a whole or any particular subset of the data. The NO_3 predictions for the northwest region showed P1 to be better than P2, but this is attributed to statistical fluctuations. The one exception appears to be when the number of days in the selected sample has less than one-third of the total number of days. In this case P1 was better 11 times and P2 was better 7 times. When the fraction of days sampled was greater than one-third, then P2 performed much better than P1, having the better prediction 11 out of 14 times.

15. Summary and Conclusions

From the data presented in this addendum, the following conclusions can be drawn.

1. With the exception that some of the very high readings in 1982 were not seen in 1983, the SO_4 and NO_3 measurements in 1983 appear to be comparable with the 1982 readings.

2. For the precipitation collected in 1983, conditions were warmer and more moist with the rain being more widespread than in 1982. The

Table 14.1: Deposition results using weighting averaging for 1982.

REGION	MONTHS	OBSERVED DEPOSITION	PREDICTION ONE	PREDICTION TWO	NO. of DAYS SAMPLE	SET
southwest	SO_4 warm	1699.530	1922.500	1754.060	27	50
	NO_3 warm	271.020	312.510	285.100	29	60
	SO_4 cold	1087.860	1174.820	1015.400	32	85
	NO_3 cold	236.777	271.394	264.987	31	84
central	SO_4 warm	1391.590	1304.690	1104.570	23	66
	NO_3 warm	154.667	169.881	131.031	21	61
	SO_4 cold	702.783	835.454	688.642	25	77
	NO_3 cold	183.780	174.262	196.468	17	64
southeast	SO_4 warm	1004.670	905.640	987.834	17	41
	NO_3 warm	139.341	159.480	143.585	18	46
	SO_4 cold	939.055	1084.560	877.920	16	62
	NO_3 cold	155.186	152.910	147.631	12	49
northwest	SO_4 warm	646.690	543.240	539.745	15	58
	NO_3 warm	105.258	98.300	100.621	16	69
	SO_4 cold	245.207	148.838	244.141	10	47
	NO_3 cold	53.576	49.730	72.145	12	51

Table 14.2: Deposition results using weighting averaging for 1983.

REGION	MONTHS	OBSERVED DEPOSITION	PREDICTION ONE	PREDICTION TWO	NO. of DAYS SAMPLE	SET
southwest	SO_4 warm	1548.840	1520.490	1433.490	27	48
	NO_3 warm	165.424	155.737	134.230	23	45
	SO_4 cold	730.594	629.815	695.282	22	57
	NO_3 cold	133.634	110.604	111.290	22	57
central	SO_4 warm	1136.850	889.920	914.942	19	51
	NO_3 warm	141.235	96.441	101.769	17	45
	SO_4 cold	626.560	604.796	507.079	16	64
	NO_3 cold	145.667	163.950	148.751	13	58
southeast	SO_4 warm	1495.060	1930.680	1681.020	23	53
	NO_3 warm	209.851	239.801	248.445	23	57
	SO_4 cold	1010.660	845.205	1032.380	18	69
	NO_3 cold	217.789	292.370	244.205	22	66
northwest	SO_4 warm	627.375	695.720	511.796	15	54
	NO_3 warm	105.629	92.270	87.985	16	67
	SO_4 cold	206.600	162.240	155.729	6	36
	NO_3 cold	25.718	23.230	18.889	3	27

Table 14.3: Deposition errors using the statistical model based on the combined 1982-83 data set

ABSOLUTE FRACTIONAL ERROR

DATA SET	SO_4 PREDICTION ONE	SO_4 PREDICTION TWO	NO_3 PREDICTION ONE	NO_3 PREDICTION TWO	BEST PREDICTION ONE	BEST PREDICTION TWO
whole	0.15	0.10	0.13	0.14	14	18
southwest	0.13	0.15	0.15	0.13	4	4
central	0.09	0.06	0.13	0.13	2	6
southeast	0.18	0.06	0.16	0.10	2	6
northwest	0.22	0.15	0.09	0.21	6	2
warm months	0.14	0.12	0.14	0.14	8	8
cold months	0.17	0.08	0.13	0.14	6	10
1982	0.16	0.07	0.09	0.11	6	10
1983	0.15	0.14	0.17	0.17	8	8
<0.35 sampled	0.16	0.12	0.11	0.14	11	7
>0.35 sampled	0.14	0.08	0.16	0.15	3	11

warmer airmasses (mT, mP) were more in evidence in 1983. Also there were more easterly winds during the precipitation in 1983 than 1982.

3. High episodes of SO_4 and NO_3 concentrations were associated with 24 hr 850 mb trajectories originating in the WSW at ranges less than 400 km and 24 hr surface trajectories originating in the SSW to ESE. Also, high SO_4 readings were associated with warm fronts, mT and mP airmasses, convective rain situations, surface and 850 mb winds from the WSW to SSE, high surface temperatures, dewpoints, precipitable water, and total totals index, and low wind speeds, rainfall amounts and area of precipitation. High NO_3 readings were also associated with low surface temperatures, dewpoints,wind speeds, rainfall amounts, and area of precipitation.

4. The statistical model performed more poorly with the 2 years data. The amount of variance explained by the model dropped from about two-thirds to one-half with the addition of the second year of data indicating that the extra data added more noise to the set since the relationship among the SO_4 and the NO_3 measurements and the meteorological variables was not sufficiently well established with the data at hand.

5. The experiments to predict annual deposition showed that overall there was no advantage to using the categorizations of the days based on the statistical model and that the errors were of the order of 10 to 15%. However, predictions of annual deposition using the use of categorizations of the days when the selected sample contained less than one-third of the total number of days was marginally better than without using the categorizations, but not a statistically significant level.

Appendix G

The following is a summary of the data available for the 4 regions (Southwest (SW), Central (CE), Southeast (SE), and Northwest (NW)). Sulfate, nitrate, and APIOS rainfall data are averages from the APIOS stations which reported precipitation on a particular day. For the discrete variables the first number is the number of observations of a given category followed by its percentage of the available observations in brackets. For the continuous variables, the mean and standard deviation (SD) is given. Missing data (indicated by MSG) refers to either the fact that data were not available, a reliable determination of the variable could not be made with the data available (e.g. predominant cloud type), or there were no data (e.g. no rainfall reports).

Table G1: A summary of the meteorological data collected.

	SW	CE	SE	NW
TOTAL NO OF OBS	137	153	132	131
SYNOPTIC TYPE				
WARM FRONT	36 (26)	29 (19)	26 (20)	21 (16)
COLD FRONT	24 (18)	34 (22)	22 (17)	21 (16)
STATIONARY FRONT	9 (7)	14 (9)	14 (11)	11 (8)
OCCLUDED LOW	43 (31)	45 (29)	41 (31)	66 (50)
COLD LOW	3 (2)	7 (5)	8 (6)	2 (2)
AIRMASS	18 (13)	21 (14)	15 (11)	9 (7)
WARM AND COLD FNTS	4 (3)	3 (2)	6 (5)	1 (1)
AIRMASS				
CA	13 (9)	19 (12)	16 (12)	21 (16)
CMA	5 (4)	9 (6)	4 (3)	6 (5)
MA	16 (12)	20 (13)	15 (11)	20 (15)
MP	5 (4)	5 (3)	3 (2)	9 (7)
MT	2 (1)	0	3 (2)	2 (2)
CA CMA	2 (1)	7 (5)	2 (2)	5 (4)
CA MA	10 (7)	13 (9)	11 (8)	21 (16)
CMA MA	19 (14)	19 (12)	20 (15)	6 (5)
MA MP	46 (34)	42 (27)	43 (33)	21 (16)
MP MT	19 (13)	19 (12)	15 (11)	19 (15)
MSG	0	0	0	1

850 MB TRAJECTORY

	SW	CE	SE	NW
24 HR SECTOR				
NNW	5 (4)	3 (2)	5 (4)	15 (12)
WNW	30 (25)	39 (27)	17 (14)	24 (19)
WSW	49 (40)	52 (36)	45 (37)	39 (30)
SSW	28 (23)	32 (22)	30 (25)	30 (23)
SSE	4 (3)	8 (6)	13 (11)	9 (7)
ESE	3 (2)	5 (3)	6 (5)	2 (2)
ENE	1 (1)	3 (2)	3 (2)	6 (5)
NNE	2 (2)	3 (2)	2 (2)	4 (3)
MSG	15	8	11	2
24 HR RANGE (KM)				
<200	0	3 (2)	4 (3)	11 (9)
200-400	17 (14)	18 (12)	10 (8)	39 (30)
400-600	39 (32)	40 (28)	34 (28)	41 (32)
600-800	31 (25)	42 (29)	37 (31)	25 (19)
800-1000	16 (13)	16 (11)	19 (16)	10 (8)
1000-1200	9 (7)	18 (12)	13 (11)	2 (2)
1200-1400	10 (8)	7 (5)	3 (2)	1 (1)
1400-1600	0	1 (1)	1 (1)	0
MSG	15	8	11	2
48 HR SECTOR				
NNW	9 (11)	6 (5)	4 (5)	7 (8)
WNW	20 (24)	39 (33)	20 (23)	24 (26)
WSW	42 (50)	40 (34)	42 (48)	23 (24)
SSW	6 (7)	14 (12)	8 (9)	24 (26)
SSE	4 (5)	9 (8)	9 (10)	5 (5)
ESE	1 (1)	4 (3)	1 (1)	3 (3)
ENE	1 (1)	4 (3)	2 (2)	4 (4)
NNE	1 (1)	1 (1)	2 (2)	4 (4)
MSG	53	36	44	37

	SW	CE	SE	NW
48 HR RANGE (KM)				
<200	2 (2)	2 (2)	1 (1)	5 (5)
200-400	6 (7)	4 (3)	7 (8)	9 (10)
400-600	7 (8)	9 (8)	6 (7)	12 (13)
600-800	15 (18)	18 (15)	10 (11)	29 (31)
800-1000	23 (27)	23 (20)	15 (17)	18 (19)
1000-1200	9 (11)	20 (17)	14 (16)	14 (15)
1200-1400	12 (14)	21 (18)	13 (15)	4 (4)
1400-1600	8 (10)	11 (9)	9 (10)	3 (3)
1600-1800	2 (2)	7 (6)	8 (9)	0
1800-2000	0	2 (2)	4 (4)	0
2000-2200	0	0	1 (1)	0
MSG	53	36	44	37
SURFACE TRAJECTORY				
24 HR SECTOR				
NNW	7 (6)	7 (5)	8 (6)	14 (12)
WNW	19 (17)	20 (14)	10 (8)	5 (4)
WSW	13 (12)	24 (17)	24 (20)	9 (8)
SSW	27 (24)	29 (20)	26 (21)	27 (22)
SSE	20 (18)	20 (14)	13 (10)	28 (23)
ESE	10 (9)	29 (20)	19 (15)	16 (13)
ENE	10 (9)	4 (3)	13 (11)	12 (10)
NNE	5 (4)	11 (8)	10 (8)	9 (8)
MSG	26	9	9	11
24 HR RANGE (KM)				
<200	11 (10)	9 (6)	8 (6)	16 (13)
200-400	27 (24)	30 (21)	26 (21)	39 (32)
400-600	26 (23)	28 (19)	24 (19)	24 (20)
600-800	25 (23)	42 (29)	32 (26)	20 (17)
800-1000	12 (11)	20 (14)	21 (17)	16 (13)
1000-1200	7 (6)	12 (8)	12 (10)	4 (3)
1200-1400	2 (2)	3 (2)	0	0
1400-1600	1 (1)	0	0	0
MSG	26	9	9	12

SURFACE TRAJECTORY	SW	CE	SE	NW
48 HR SECTOR				
NNW	9 (10)	18 (15)	8 (9)	10 (10)
WNW	13 (15)	19 (16)	10 (11)	4 (4)
WSW	12 (14)	18 (15)	17 (19)	3 (3)
SSW	21 (24)	16 (13)	15 (17)	25 (24)
SSE	8 (9)	14 (12)	4 (4)	22 (21)
ESE	9 (10)	16 (13)	10 (11)	16 (15)
ENE	5 (6)	6 (5)	11 (12)	18 (17)
NNE	11 (12)	13 (11)	14 (16)	5 (5)
MSG	49	33	43	28
48 HR RANGE (KM)				
<200	5 (6)	9 (8)	3 (3)	8 (8)
200-400	11 (12)	13 (11)	12 (13)	16 (16)
400-600	21 (24)	18 (15)	16 (18)	22 (21)
600-800	23 (26)	27 (22)	17 (19)	21 (20)
800-1000	10 (11)	23 (19)	23 (26)	15 (15)
1000-1200	7 (8)	13 (11)	6 (7)	18 (17)
1200-1400	8 (9)	10 (8)	9 (10)	2 (2)
1400-1600	0	7 (6)	3 (3)	1 (1)
1600-1800	3 (3)	0	0	0
MSG	49	33	43	28
TYPE OF PRECIPITATION				
CONTINUOUS	62 (46)	62 (41)	65 (51)	60 (50)
CONVECTIVE	72 (54)	90 (59)	63 (49)	60 (50)
MSG	3	1	4	11
NATURE OF PRECIPITATION				
RAIN	97 (72)	95 (62)	93 (73)	82 (68)
SNOW	20 (15)	43 (28)	12 (9)	21 (18)
FREEZING	5 (4)	1 (1)	1 (1)	5 (4)
MIXED	12 (9)	13 (9)	22 (17)	12 (10)
MSG	3	1	4	11

	SW	CE	SE	NW
PREDOMINANT CLOUDS				
TOWERING CUMULUS	7 (5)	9 (6)	2 (2)	11 (11)
ALTOCUMULUS	4 (3)	3 (2)	3 (2)	2 (2)
ALTOSTRATUS	1 (1)	2 (1)	0	0
CUMULONIMBUS	22 (17)	20 (13)	21 (17)	17 (18)
CUMULUS	10 (8)	10 (7)	2 (2)	3 (3)
NIMBOSTRATUS	21 (16)	10 (7)	11 (9)	1 (1)
STRATOCUMULUS	48 (36)	63 (42)	75 (59)	49 (51)
STRATUS	19 (14)	32 (21)	13 (10)	13 (14)
MSG	5	4	5	35
SURFACE WIND SECTOR				
NNW	9 (7)	13 (8)	11 (8)	12 (9)
WNW	16 (12)	22 (14)	11 (8)	15 (12)
WSW	24 (18)	21 (14)	30 (23)	15 (12)
SSW	22 (16)	22 (14)	21 (16)	12 (9)
SSE	12 (9)	29 (19)	13 (10)	18 (14)
ESE	33 (24)	26 (17)	11 (8)	15 (12)
ENE	16 (12)	10 (7)	18 (14)	31 (24)
NNE	3 (2)	10 (7)	16 (12)	9 (7)
CALM	1 (1)	0	1 (1)	2 (2)
MSG	1	0	0	2
850 MB WIND SECTOR				
NNW	8 (7)	13 (10)	10 (9)	17 (15)
WNW	23 (19)	27 (21)	19 (16)	30 (27)
WSW	32 (27)	48 (37)	51 (44)	26 (23)
SSW	28 (24)	28 (21)	25 (21)	14 (12)
SSE	10 (8)	9 (7)	7 (6)	9 (8)
ESE	11 (9)	1 (1)	1 (1)	7 (6)
ENE	2 (2)	2 (2)	1 (1)	4 (4)
NNE	4 (3)	3 (2)	3 (3)	6 (5)
MSG	19	22	15	18

	SW	CE	SE	NW
CLOUD BASE HEIGHT (M)				
MEAN	671	651	689	784
SD	548	472	441	501
MSG	5	4	5	35
SURFACE TEMPERATURE (°C)				
MEAN	8.4	7.4	8.7	8.2
SD	9.1	9.2	8.6	9.1
MSG	1	0	0	2
SURFACE DEWPOINT (°C)				
MEAN	6.2	5.0	6.5	6.1
SD	9.2	9.0	8.0	9.0
MSG	1	0	0	2
SURFACE WIND SPEED (m/s)				
MEAN	9.3	8.6	8.0	12.7
SD	4.9	4.2	4.4	4.2
MSG	1	0	0	1
850 MB TEMPERATURE (°C)				
MEAN	4.3	3.3	4.7	5.2
SD	9.7	9.5	8.1	9.0
MSG	15	18	14	12
850 MB WIND SPEED (kts)				
MEAN	24	24	27	19
SD	12	11	13	8
MSG	19	22	15	18
PRECIPITABLE WATER (mm)				
MEAN	22.4	19.9	22.5	20.4
SD	12.9	11.3	11.2	11.0
MSG	19	25	17	12

	SW	CE	SE	NW
TOTAL TOTALS				
MEAN	17.4	15.8	20.7	17.6
SD	18.7	15.0	12.6	14.7
MSG	18	23	17	12
DURATION OF PRECIPITATION (hr)				
MEAN	7.8	7.8	7.7	8.1
SD	5.0	5.4	5.3	6.3
MSG	42	70	51	77
PRECIPITATION RATE (mm/hr)				
MEAN	1.1	1.2	1.2	1.0
SD	1.0	1.5	1.2	1.0
MSG	42	71	51	77
DAILY AMOUNT (mm)				
MEAN	7.3	6.7	7.1	7.1
SD	5.8	5.2	5.4	6.1
MSG	0	0	0	7
% OF STNS WITH PRECIP				
MEAN	0.76	0.78	0.78	0.54
SD	0.22	0.21	0.22	0.27
SO_4 (mg/l)				
MEAN	3.30	2.88	3.05	1.24
SD	1.88	3.02	2.88	1.06
MSG	2	0	0	1
NO_3 (mg/l)				
MEAN	0.61	0.59	0.57	0.24
SD	0.44	0.72	0.64	0.22
MSG	1	0	1	1
APIOS PRECIPITATION (mm)				
MEAN	8.4	7.5	8.4	8.7
SD	8.3	9.2	7.2	8.8
MSG	1	0	2	3

Appendix H

Table H1: Sulfate and Nitrate data as a function of the categories of the discrete variables for 1983.

	SO_4		NO_3	
	MEAN	SD	MEAN	SD
SYNOPTIC TYPE				
WARM FRONT	4.06	1.78	0.69	0.49
COLD FRONT	2.98	1.45	0.50	0.34
STATIONARY FRONT	2.55	1.76	0.44	0.29
OCCLUDED LOW	3.05	1.84	0.59	0.43
COLD LOW	4.23	1.70	0.66	0.31
AIRMASS	2.80	2.43	0.65	0.59
WARM AND COLD FRONT	4.50	1.38	0.78	0.28
AIRMASS				
CA	1.90	2.06	0.61	0.53
CMA	3.38	2.32	0.88	0.81
MA	2.93	1.70	0.52	0.42
MP	3.91	1.93	0.64	0.47
MT	5.47	3.22	0.64	0.23
CA CMA	1.10	0.14	0.49	0.00
CA MA	2.76	1.49	0.62	0.49
CMA MA	3.74	2.11	0.79	0.57
MA MP	3.39	1.71	0.50	0.33
MP MT	4.08	1.50	0.70	0.39
850 MB TRAJECTORY				
24 HR SECTOR				
NNW	1.81	1.71	0.71	0.65
WNW	2.45	1.35	0.52	0.42
WSW	4.10	1.92	0.67	0.45
SSW	3.32	1.61	0.56	0.39
SSE	1.97	1.43	0.34	0.35
ESE	2.48	1.72	0.70	0.77
ENE	1.74	--	0.51	--
NNE	3.97	4.85	0.89	1.24

	SO_4 MEAN	SO_4 SD	NO_3 MEAN	NO_3 SD
24 HR RANGE (KM)				
<200	--	--	--	--
200-400	2.91	1.45	0.61	0.48
400-600	3.76	1.99	0.67	0.48
600-800	3.06	2.01	0.55	0.41
800-1000	3.30	1.98	0.59	0.45
1000-1200	3.60	1.99	0.77	0.61
1200-1400	2.63	1.09	0.34	0.17
48 HR SECTOR				
NNW	1.89	1.37	0.60	0.54
WNW	2.60	1.44	0.53	0.45
WSW	3.90	2.02	0.64	0.42
SSW	3.35	2.14	0.66	0.38
SSE	3.47	1.21	0.87	0.57
ESE	0.54	--	0.01	--
NNE	7.40	--	1.77	--
48 HR RANGE (KM)				
<200	3.86	0.36	0.70	0.54
200-400	2.73	1.49	0.56	0.43
400-600	1.98	1.49	0.78	0.76
600-800	4.00	1.76	0.69	0.40
800-1000	3.87	2.26	0.72	0.54
1000-1200	4.01	2.06	0.64	0.49
1200-1400	2.37	1.48	0.42	0.24
1400-1600	2.54	2.06	0.52	0.28
1600-1800	2.95	0.28	0.49	0.18
SURFACE TRAJECTORY				
24 HR SECTOR				
NNW	2.19	2.76	0.53	0.70
WNW	2.26	1.46	0.46	0.46
WSW	3.27	1.40	0.62	0.44
SSW	4.12	1.80	0.75	0.43
SSE	3.96	2.02	0.62	0.30
ESE	3.05	1.75	0.49	0.39
ENE	2.43	1.53	0.49	0.46
NNE	2.51	2.84	0.69	0.75

	SO_4		NO_3	
	MEAN	SD	MEAN	SD
24 HR RANGE (KM)				
<200	3.24	2.40	0.60	0.38
200-400	3.72	1.88	0.61	0.45
400-600	3.91	1.86	0.63	0.37
600-800	2.71	1.71	0.64	0.57
800-1000	2.82	2.07	0.61	0.54
1000-1200	2.41	1.49	0.46	0.35
1200-1400	1.18	0.82	0.30	0.08
SURFACE TRAJECTORY				
48 HR SECTOR				
NNW	3.12	2.73	0.52	0.34
WNW	2.41	1.64	0.57	0.62
WSW	2.66	1.28	0.56	0.39
SSW	3.89	1.97	0.66	0.51
SSE	3.55	1.93	0.42	0.27
ESE	3.29	2.56	0.73	0.44
ENE	4.07	1.37	0.83	0.46
NNE	3.32	2.64	0.75	0.67
48 HR RANGE (KM)				
<200	3.93	1.92	0.69	0.39
200-400	3.76	2.63	0.60	0.44
400-600	3.35	1.93	0.63	0.54
600-800	3.55	2.06	0.65	0.44
800-1000	3.45	1.33	0.65	0.42
1000-1200	2.71	2.06	0.63	0.65
1200-1400	2.41	2.41	0.70	0.70
1400-1600	--	--	--	--
1600-1800	0.89	0.27	0.18	0.20

	SO_4		NO_3	
	MEAN	SD	MEAN	SD
TYPE OF PRECIPITATION				
CONTINUOUS	2.83	1.64	0.55	0.44
CONVECTIVE	3.66	1.95	0.65	0.45
NATURE OF PRECIPITATION				
RAIN	3.69	1.73	0.60	0.42
SNOW	1.91	1.77	0.65	0.49
FREEZING	2.87	1.09	0.51	0.39
MIXED	2.35	1.94	0.61	0.61
PREDOMINANT CLOUDS				
TOWERING CUMULUS	2.38	1.59	0.46	0.29
ALTOCUMULUS	2.67	1.87	0.33	0.24
ALTOSTRATUS	6.58	--	0.87	--
CUMULONIMBUS	3.81	1.20	0.52	0.22
CUMULUS	3.34	1.53	0.66	0.50
NIMBOSTRATUS	2.42	1.19	0.45	0.28
STRATOCUMULUS	3.64	2.21	0.73	0.53
STRATUS	2.95	1.99	0.65	0.58
SURFACE WIND SECTOR				
CALM	2.05	--	0.45	--
NNW	2.03	1.25	0.51	0.52
WNW	2.91	2.32	0.54	0.45
WSW	3.14	1.94	0.64	0.50
SSW	3.79	1.56	0.63	0.47
SSE	4.11	1.68	0.57	0.28
ESE	3.62	1.58	0.69	0.46
ENE	2.80	2.19	0.53	0.41
NNE	2.07	0.46	0.43	0.19
850 MB WIND SECTOR				
NNW	3.01	2.46	0.65	0.58
WNW	2.33	1.54	0.52	0.47
WSW	4.03	1.86	0.70	0.40
SSW	3.81	1.51	0.69	0.43
SSE	2.68	1.27	0.47	0.31
ESE	2.63	1.64	0.38	0.38
ENE	2.02	0.24	0.23	0.02
NNE	3.00	2.05	0.80	0.67

Table H.2: Correlation coefficients, significance probabilities, and number of observations between SO_4, NO_3, and the continuous meteorological variables for 1983.

CORRELATION COEFFICIENTS/PROB > R UNDER H0:RHO=0/NUMBER OF OBSERVATIONS

	SO_4	NO_3		SO_4	NO_3
CLOUD BASE HEIGHT	0.229 0.01 130	0.075 0.40 131	PRECIPITABLE WATER	0.232 0.012 116	-0.068 0.46 118
SURFACE TEMPERATURE	0.266 0.0019 134	-0.049 0.57 135	TOTAL TOTALS INDEX	0.250 0.01 117	-0.050 0.59 119
SURFACE DEWPOINT	0.250 0.0036 134	-0.058 0.50 135	DURATION OF PRECIP	0.147 0.16 94	0.195 0.06 95
SURFACE WIND SPEED	-0.219 0.01 134	-0.205 0.02 135	AVERAGE PRECIP RATE	0.206 0.50 94	0.267 0.01 95
850 MB TEMPERATURE	0.328 0.0003 120	-0.021 0.82 122	AMOUNT OF PRECIP	-0.198 0.021 135	-0.376 0.0001 136
850 MB WIND SPEED	-0.011 0.91 116	-0.061 0.51 118	AREA OF PRECIP	-0.105 0.22 135	-0.261 0.0022 136

Appendix I

Table I1: The frequency distribution of the categorical variables for the top 30% of the SO_4 and NO_3 readings for 1983.

	SO_4		NO_3	
	NO	PCT	NO	PCT
SYNOPTIC TYPE				
WARM FRONT	13	32	13	32
COLD FRONT	6	15	6	15
STATIONARY FRONT	1	2	2	5
OCCLUDED LOW	14	34	11	27
COLD LOW	2	5	2	5
AIRMASS	3	7	5	12
WARM AND COLD FRONT	2	5	2	5
AIRMASS				
CA	1	2	3	7
CMA	1	2	1	2
MA	5	12	5	12
MP	2	5	1	2
MT	1	2	1	2
CA CMA	0	0	0	0
CA MA	3	7	4	10
CMA MA	7	17	8	20
MA MP	14	34	9	22
MP MT	7	17	9	22

	SO_4		NO_3	
	NO	PCT	NO	PCT
850 MB TRAJECTORY				
24 HR SECTOR				
NNW	1	3	2	6
WNW	3	8	5	14
WSW	22	61	20	56
SSW	8	22	6	17
SSE	0	0	1	3
ESE	1	3	1	3
NNE	1	3	1	3
24 HR RANGE (KM)				
<200	0	0	0	0
200-400	5	14	7	19
400-600	14	39	13	36
600-800	9	25	7	19
800-1000	3	8	4	11
1000-1200	4	11	5	14
1200-1400	1	3	0	0
1400-1600	0	0	0	0
48 HR SECTOR				
NNW	1	4	2	7
WNW	3	12	4	14
WSW	15	60	15	54
SSW	3	12	3	11
SSE	2	8	2	7
NNE	1	4	1	4
48 HR RANGE (KM)				
<200	1	4	1	4
200-400	2	8	3	11
400-600	1	4	2	7
600-800	8	32	6	21
800-1000	8	32	9	32
1000-1200	3	12	3	11
1200-1400	1	4	1	4
1400-1600	1	4	3	11
1600-1800	0	0	0	0

	SO_4		NO_3	
	NO	PCT	NO	PCT
SURFACE TRAJECTORY				
24 HR SECTOR				
NNW	1	3	1	3
WNW	1	3	3	9
WSW	3	9	3	9
SSW	12	35	13	41
SSE	11	32	5	16
ESE	2	6	2	6
ENE	3	9	3	9
NNE	1	3	2	6
24 HR RANGE (KM)				
<200	3	9	4	12
200-400	11	32	9	28
400-600	12	35	7	22
600-800	4	12	7	22
800-1000	3	9	4	12
1000-1200	1	3	1	3
1200-1400	0	0	0	0
SURFACE TRAJECTORY				
48 HR SECTOR				
NNW	3	10	3	11
WNW	2	7	4	15
WSW	1	3	2	7
SSW	9	31	6	22
SSE	3	10	1	4
ESE	3	10	4	15
ENE	4	14	3	11
NNE	4	14	4	15
48 HR RANGE (KM)				
<200	2	7	2	7
200-400	4	14	2	7
400-600	7	24	5	19
600-800	9	31	11	41
800-1000	3	10	2	7
1000-1200	2	7	2	7
1200-1400	2	7	3	11
1400-1600	0	0	0	0

	SO_4		NO_3	
	NO	PCT	NO	PCT
TYPE OF PRECIPITATION				
CONTINUOUS	13	32	16	41
CONVECTIVE	27	68	23	59
NATURE OF PRECIPITATION				
RAIN	36	90	29	74
SNOW	2	5	5	13
FREEZING	0	0	2	5
MIXED	2	5	3	8
PREDOMINANT CLOUDS				
TOWERING CUMULUS	1	2	1	3
ALTOCUMULUS	1	2	0	0
ALTOSTRATUS	1	2	1	3
CUMULONIMBUS	8	20	5	13
CUMULUS	3	8	4	11
NIMBOSTRATUS	3	8	3	8
STRATOCUMULUS	19	48	18	47
STRATUS	4	10	6	16
SURFACE WIND SECTOR				
NNW	1	2	2	5
WNW	4	10	4	10
WSW	7	18	7	18
SSW	7	18	7	18
SSE	5	12	4	10
ESE	11	28	12	30
ENE	5	12	4	10
NNE	0	0	0	0
850 MB WIND SECTOR				
NNW	2	6	3	9
WNW	3	9	3	9
WSW	13	38	14	40
SSW	12	35	10	29
SSE	1	3	2	6
ESE	1	3	1	3
ENE	0	0	0	0
NNE	2	6	2	6

Table I.2. Averages and standard deviations (SD) of the continuous meteorological variables for the top 30% readings of the SO_4 and NO_3.

	SO_4		NO_3	
	MEAN	SD	MEAN	SD
CLOUD BASE HEIGHT	874	650	745	540
SURFACE TEMPERATURE	10.1	8.1	8.7	9.4
SURFACE DEWPOINT	7.9	8.1	6.3	9.2
SURFACE WIND SPEED	8.1	4.3	8.0	4.4
850 MB TEMPERATURE	7.1	8.4	4.8	10.3
850 MB WIND SPEED	25	13	22	11
PRECIPITABLE WATER	24.8	12.7	22.5	14.6
TOTAL TOTALS	21.8	22.1	18.5	22.2
DURATION OF PCPN	6.6	3.3	7.0	3.7
AVERAGE RAINRATE mm/hr	0.9	0.9	0.9	0.8
AMOUNT OF PCPN	5.8	5.5	5.0	5.1
% STNS WITH PCPN	0.74	0.18	0.70	0.21

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